PREDATION BY RESIDENT FISH ON JUVENILE SALMONIDS IN

JOHN DAY RESERVOIR, **1983**-**1986**

Volume II - Supplemental Papers and Data Documentation

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PREFACE

This document is a supplement to the final report for two research projects, funded by the Bonneville Power Administration (BPA) Project No. 82-3 conducted by the U.S. Fish and Wildlife Service (FWS) and Project No. **82**-**12** conducted by the Oregon Department of Fish and Wildlife (ODFW). Section I contains the research papers prepared by FWS and Section II the research papers prepared by ODFW; these papers describe how we addressed project objectives and document procedures used to obtain the study results reported in the Final Report (Volume 1). At the end of each section we also include information on how to find and use the data files and programs developed by each project.

SECTION I

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Project No. 82-3

A Prototype Water Reuse System

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Abstract

A small scale water reuse system (150 L/min) was developed to create an environment for making observations on fish under a variety of temperature regimes. Key concerns of disease control, water quality, temperature control, and efficiency and ease of operation were addressed. Northern squawfish (Ptychocheilus oregonensis) were held at loading densities ranging from 0.11 to 0.97 kg/L/min and at temperatures 10 to 20 C (+ 0.5) for six months with no disease problems or degradation of water quality in the system, and minimal system maintenance.

Introduction

In 1982 the Willard Field Station of the U.S. Fish and Wildlife Service initiated predation research on cool and warm water fishes of the Columbia River and needed a wet laboratory to perform controlled digestion rate experiments on live predator fishes. Clean water was plentiful from the Little White Salmon River, a nearby tributary to the lower Columbia River, and also from nearby springs but was extremely cold, rarely exceeding 8 C. In addition, the Little White Salmon National Fish Hatchery was located 8 km downstream from the proposed wet laboratory and could not tolerate diseases introduced from non-indigenous fish studied in the laboratory.

To meet those needs a water reuse system was designed to minimize costs of heating and sterilizing water, while providing a highly controlled environment for conducting research studies. This paper describes the design and operation of a small scale reuse system that has operated successfully for over two years. An extensive review of literature and existing systems was conducted prior to construction of the system and provided the basis for system design (Lucchetti and Grey, In Press).

Methods and Materials

To prevent disease problems within the system, and in the downstream hatchery, we treated both the effluent and reuse water. Sterilization was effected by two in-line UV units, each providing a minimum dose of 30,000 W/second/cm2 (193,548 W/second/in2) at 15 L/minute (4 gal/minute) at 70% bulb efficiency. One unit was used to treat recirculating water and the other to treat effluent water.

Our system integrated ion exchange and biofiltration for ammonia removal by using clinoptilolite as a medium for colonization of nitrifying bacteria. The use of clinoptilolite provided initial ammonia removal capabilities before nitrification became established, as well as insurance against failure of the nitrification process. Addition of a commercially available solution of microorganisms ensured that both types of bacteria required would be present at the proper time and in the required quantities. This was additionally important to affect loss of beneficial nitrifying bacteria when reuse water recirculated through the sterilization units. The microoogranisms were added downstream of the sterilization units and upstream of the filter.

We used a packed column for oxygenation and degassing because it was simple and efficient. The column consisted of a polyvinyl chloride (PVC) pipe (1.5 m x 21 cm inside diameter) (4.9 Ft X **8.3** in) open at the top and about three-quarters full of 2.5 cm (1 in) koch rings. The pipe was open at the top to allow gas exchange and was capable of treating at least **150** L/minute **(40** gal/minute) (D.E. Owsley, Dworshak/ Kooskia National Fish Hatchery Complex, P.O. Box 18, Ahsahka, Idaho, **83520,** personal communication). Other methods, including mechanical agitators, oxygen pumps, and aspirators were avoided because of the potential for mechanical and plumbing failure. A pressurized sand filter, **1** m **(3.3** ft) in diameter, treated only reuse water, because our fresh (i.e. make-up) water was extremely clean. Temperature control was achieved by using a commercially available in-line 18 KN elecctrical heater for warming and a small amount of cold spring or river water for cooling. The later provided waste water exchange and fresh water replenishment.

The system was assembled from materials that were on hand or readily available from commercial dealers. All plumbing was PVC, except for four 5 cm (2 in) brass valves and an aluminum foot and float valve. All wetted parts in the circulation heater and centrifugal pumps were either stainless steel or iron and all other metal or concrete surfaces were coated with neoprene rubber. The biofilter and sump were contained in a concrete pit (4.9 x 0.5 x 1 m) (16 X 1.6 X 3.3 ft). A water chlorinator was also added to the system to treat the effluent water discharged into the Little White Salmon River in order to prevent introduction of disease in the hatchery located 8 km downstream. Plumbing to bypass each feature in the system was incorporated. The pathway of water through the system is shown in Fig. **1.**

Our water reuse system was "conditioned" with eight adult (>250 mm (9.8 in) in total length) northern squawfish collected from the Columbia River for use in digestion rate experiments. Total flow was maintained at 150 L/minute (40 gal/minute), equally distributed to each tank, and included a 5% fresh (and waste) water exchange. The sand filter was backwashed once or twice a week, depending on pressure buildup.
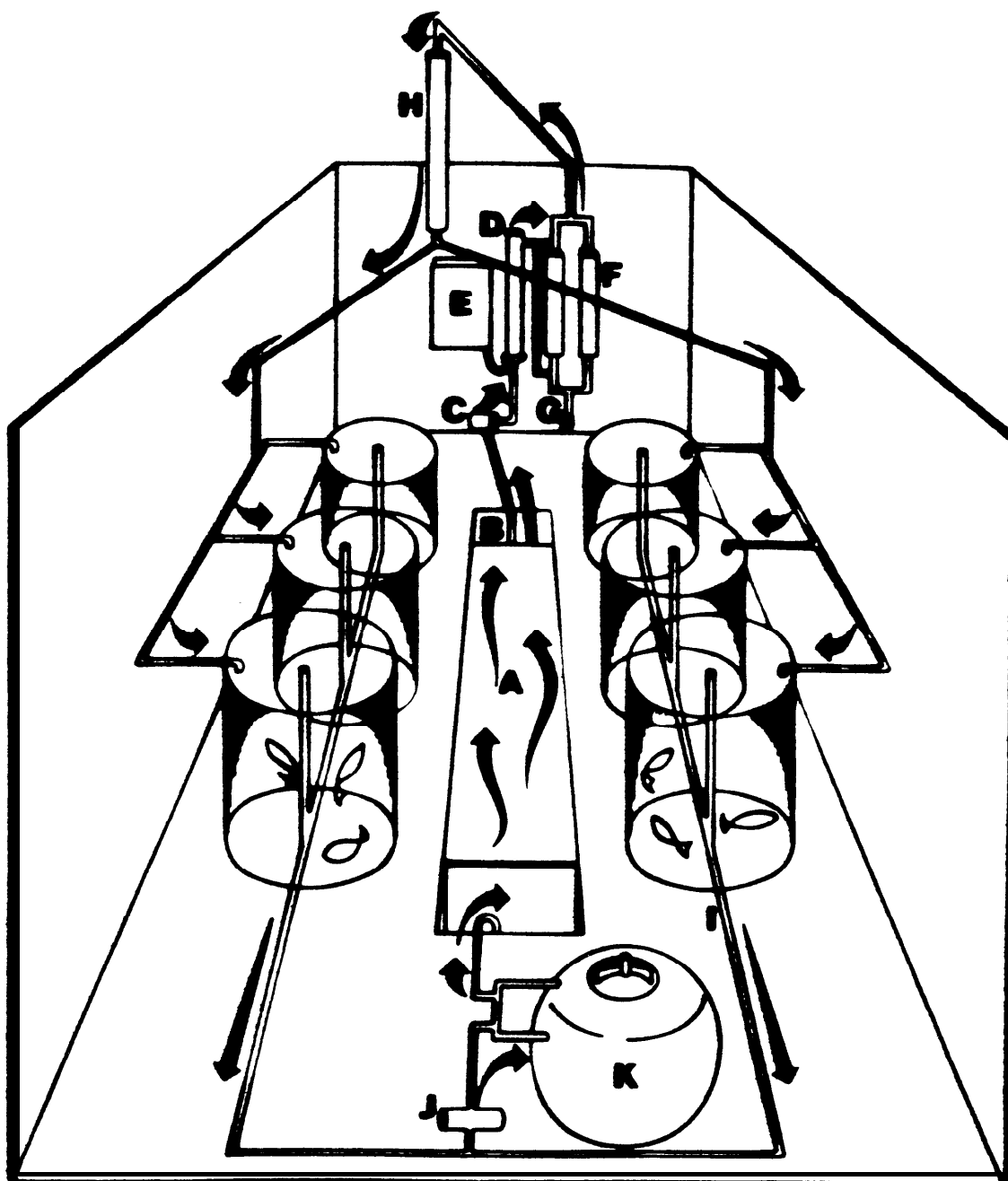
Figure I. Diagramatic view of an operational water reuse system. The pathway of water through the system was as follows: overflow water from biofilter (A) was drawn from sump (B) by centrifugal pump (C) and delivered to a-circulation heater (D) regulated by heater control panel (E). Water was then treated by UV sterilization units (F) and released as effluent (G), or directed to a packed column (H), and distributed by gravity feed to fish holding tanks. Centrifugal pump (J) distributed tank overflow water (I) through the pressurized sand filter (K) to the biofilter (A), Arrows show direction of flow.

Regular monitoring of selected chemical variables was begun in the week starting July 3 (week 1), when we introduced 84 northern squawfish, total weight, 50 kg (110 lbs), at a loading density of 0.33 kg/L/minute (2.75 lb/gal/minute). Little maintenance work was done on the biofilter until week 20, when ammonia levels began rising as a result of channelization in the filter; this situation was remedied by gently agitating the top 15 to 20 cm (5.9 to 7.9 in) cm of clinoptilolite with a rake. Temperatures were maintained at experimental levels to within + 0.5C (0.9 F). Dissolved oxygen (DO), conductivity, and pH were monitored with a Hydrolab[1] series 8000 placed in one of seven fish holding tanks. Starting in week 21, DO was measured with a YSI Model #58 meter. Ammonia nitrogen (NH_4-N), nitrite (NO_2), and nitrate (NO_3) were measured with a Hach kit model NI-8 for ammonia nitrogen and model NI-12 for nitrate and nitrite. Monitoring was done daily until week 17, thereafter, DO, conductivity, and pH were estimated weekly.

Northern squawfish in the system were fed fingerling salmon (Oncorhynchus sp.) ad libitum, 6 to 8 days per month. This diet was intended as a maintenance ration only. Loading density fluctuated as northern squawfish were sacrificed and replaced during the study. The body and viscera of sacrificed northern squawfish were examined for signs of starvation and disease.

Performance of System

Water quality was adequate throughout the 25 week observation period (Fig. 2) at loading densities averaging 0.51 kg/L (4.26 lb/gal). The DO varied with water temperature and ranged from 7.8 (week 4) to 13.1 mg/L (1.77 X 10^{-3} oz/gal) (week 16). Average pH was 6.73, as compared with 6.9 to 7.2 for the water source--indicating that nitrificatioon had caused slight acidification. Conductivity averaged 0.058 mhos/cm (0.147 mhos/in) and varied little over the course of study.

Actual ammonia production by northern squawfish in the water reuse system was not computed because it was impractical to determine the "ammonia factor" needed for equations outlined by Piper et al. (1982). Brett and Zala (1975) showed that, even after 22 days of starvation, juvenile sockeye salmon (Oncorhnychus nerka) had an ammonia output of 7.27 mg N/kg/L (4.46 X-10^{-4} oz/lb/gal) that was near the basal ammonia excretion rate (8.2 mg N/kg/L) (5.03 X 10^{-4} oz/lg/gal) of salmon fed a maintenance ration. Throughout the study, northern squawfish maintained

[1] Reference to trade names does not imply U.S. Government endorsement of commercial products.
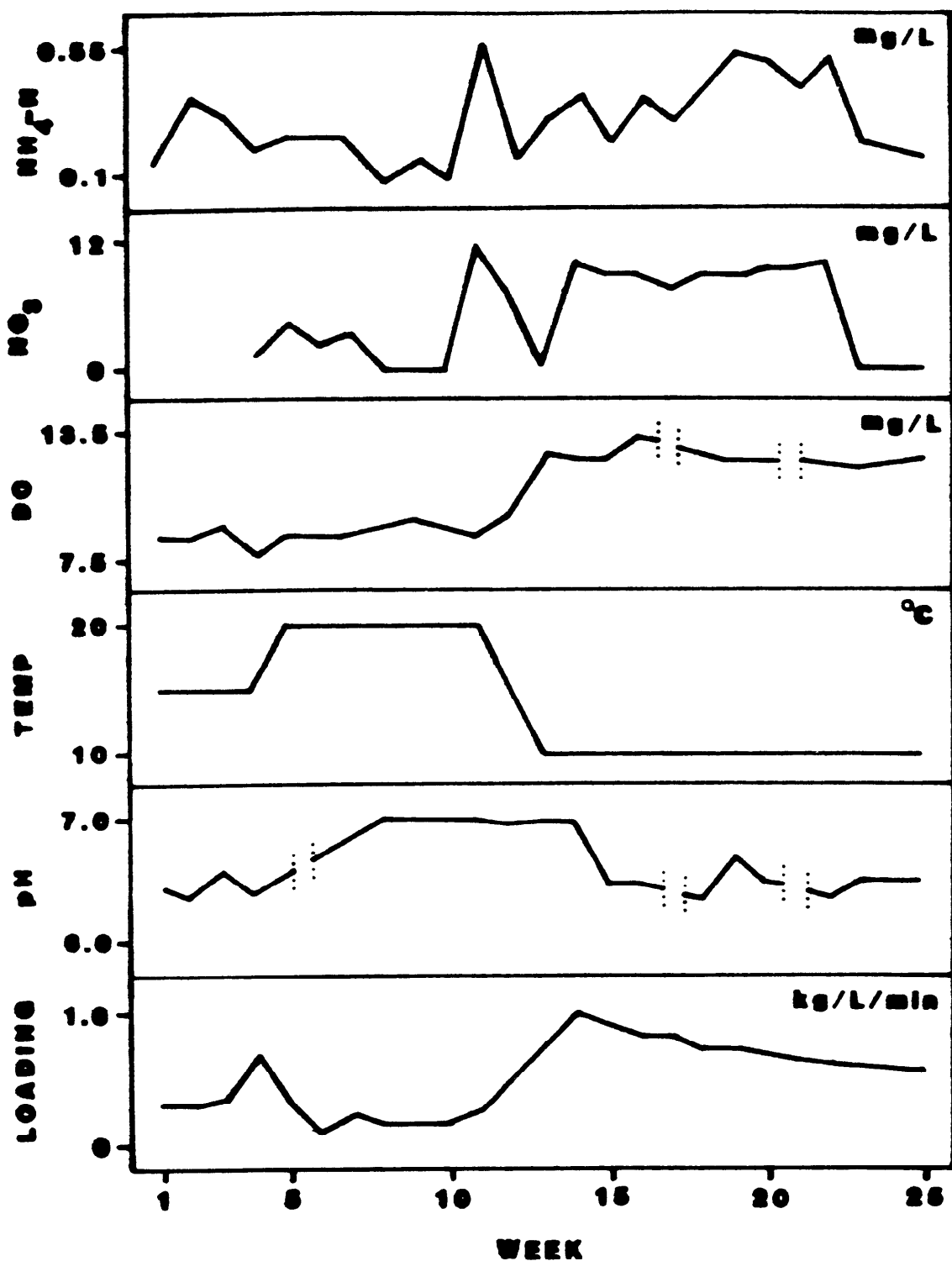
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Figure 2. Temperature, water chemistry, and loading density during 25 weeks of continuous operation of the water reuse system.

high fat content in the body cavity and showed no signs of atrophy of the gut. E.M. Dawley, (Hammond Field Station, P.O. Box 155, Hammond, Oregon, 97121, personal communication) held northern squawfish under similar conditions for 4 months without food and could not detect morphological signs of starvation; fish ate readily when offered food. Therefore, it seems likely that the basal rate of ammonia excretion by the northern squawfish should have been adequate to evaluate the system.

Ammonia nitrogen, nitrite, and nitrate levels were well below toxic levels reported for other fish species. Thurston et al. (1978) estimated 36-day median lethal concentrations (LC50) of un-ionized ammonia and nitrite for fry of cutthroat trout (Salmo clarki) to be 0.3 to 0.6 mg/L (4.06×10^{-5} to 8.11×10^{-5} oz/gal) and 0.4 mg/L (5.41×10^{-5} oz/gal), respectively. Estimates of the un-ionized portion of ammonia nitrogen during our study, based on calculations given by Emerson et al. (1975), never exceeded 2 g/L (2.70×10^{-7} oz/gal). Nitrite was generally undetectable. Nitrate was considerably lower (average of 5 mg/L) (6.76×10^{-4} oz/gal), than that reported by Colt and Armstrong (1981) to have lethal or sublethal effects on fish.

No fish disease problems developed during the study, even though the northern squawfish came from the wild and were not treated for disease before the experiments, and were repeatedly stressed by handling and sorting. Mortality associated with an infestation of Ichthyopthirius sp. did arise after the study was completed. Disinfection of the system with chlorine and quarantining of fish prior to introduction into the system has resulted in disease free operation since the end of the mortality period. C.M. Falter (University of Idaho, Moscow, Idaho, 83843, personal communication) found it difficult to maintain lake stocks of northern squawfish because the fish were infested with cestodes. Although cestodes were prevalent in virtually all northern squawfish examined, the fish never developed heavy infestations. Mats of filamentous bacteria (Sphaerotilus) and algae, as reported by other researchers (Burrows and Combs 1968; Spotte 1979), were never problems in our system. The UV treatment undoubtedly limited the concentrations of disease organisms, as well as of nitrifying bacteria, in the system Therefore addition of a small amount of commercially available bacterial solution was made to offset U.V. mortality.

Few problems in maintaining a healthy aquatic environment for studying northern squawfish were encountered with the described water reuse system. Problems that arose were generally attributable to operational. procedures. For example, high levels of ammonia detected by week 20 were corrected by gently stirring the top level of clinoptilolite to prevent fouling and channelization; up to that time, the filter medium required virtually no maintenance. This system was highly adaptable and took advantage of existing facilities, which

provided more space for fish tanks. For example, the biofilter was originally a concrete pit for housing heating pipes. The system was built at a cost of $US8,000 (1984) excluding labor.

Acknowledgements

References

Brett, J.R. and C.A. Zala. **1975.** Daily pattern of nitrogen excretion and oxygen consumption of sockeye salmon (Oncorhynchus nerka) under controlled conditions. Journal Fisheries Research Board Canada 32:2479-2486.

Burrows, R.E., and B.D. Combs. **1968.** Controlled environments for salmon propagation. Progressive Fish Culturist 30:123-136.

Colt, J.E., and D.A. Armstrong. 1981. Nitrogen toxicity to fish, crustaceans and mollusks. Pages 39-42 in L.J. Allen and E.C. Kinney, eds. Proceedings of the bioengineering symposium for fish culture. Fish Culture Section, American Fisheries Society, Bethesda, Maryland.

Emerson, K., R.C. Russo, R.E. Lund, and R.V. Thurston. **1975.** Aqueous ammonia equilibrium calculations: effect of pH and temperature. Journal Fisheries Research Board Canada 32:2379-2383.

Lucchetti, G.L., and G.A. Gray. **1988.** Water reuse systems: review of principal components. Progressive Fish-Culturist (In Press).

Spotte, S. **1979.** Fish and invertebrate culture: water management in closed system 2nd ed. Wiley-Interscience Co., New York, New York.

Thurston, R.V., R.C. Russo, and C.E. Smith. **1978.** Acute toxicity of ammonia and nitrite to cutthroat trout fry. Transactions of the American Fisheries Society **107: 361-368.**

A Method to Directly Measure Maximum Volume
of Fish Stomachs or Digestive Tracts

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ABSTRACT

     A new method for directly measuring maximum stomach or digestive tract volume of fish incorporates air injection at constant pressure with water displacement to directly measure the internal volume of a stomach or analogous structure. The method was tested with coho salmon, Oncorhynchus kisutch (Walbaum), which have a true stomach, and northern squawfish, Ptychocheilus oregonensis (Richardson), which have a modified foregut as a functional analog. Both species were collected during July-October **1987** from the Columbia River, USA. Relations between fish weight (= volume) and maximum volume of the digestive organ were best fitted to coho salmon by an allometric model and to northern squawfish by an exponential model. Least squares regression analysis of individual measurements showed less variability in the volume of coho salmon stomachs (R^2 = 0.85) than in the total digestive tracts (R^2 = 0.55) and foreguts (R^2 = **0.61)** of northern squawfish, relative to fish size. Compared to previous methods, the new technique has the advantages of accurately measuring the internal volume of a wide range of digestive organ shapes and sizes, and of having an objective measure of final inflation pressure.

I. INTRODUCTION

The relationship between fish size and the volume (capacity) of its digestive tract--or true stomach in the case of most piscivores--has three general applications to trophic research: studies of food habits; digestion and food consumption rate studies; and bioenergetics models. In food habits studies, specific food category (volume or weight) is often estimated, either subjectively or by measurement, as a percentage of total stomach contents. Describing food items in this way however, provides little information on dietary importance unless the estimate is related to stomach volume or fish size. When a food category is expressed as a percentage of stomach capacity, a mean percent volume can be calculated for the individual sample or the total percentage for the food category can be expressed as a proportion of the overall total volume of stomach contents [see Hyslope (1980) for a comprehensive review with specific applications].

Studies of digestion and food consumption rates with respect to changes in stomach fullness constitute a second application of maximum stomach volume relations (e.g. Bajkov, 1935; Windell, 1978). Daily food ration can be estimated from field observations of the diel cycle of stomach contents by modeling the time trajectory of stomach fullness (Thorpe, **1977;** Sainsbury, 1986). Since stomach distention provides stimuli for digestive processes within the gastrointestinal tract, quantification of the functional relation between stomach volume and fish weight is also important to gastric evacuation studies, which make direct comparisons between fish of different sizes by feeding a constant ration (e.g. Jobling et al., 1977; Flowerdew & Grove 1979).

Finally, in a bioenergetics model, physiological maximum ration is used to determine the upper bound in growth potential of a fish population (Stewart & Binkowski, 1986). This maximum level, obtained from laboratory experiments on ad libitum feeding rates, is adjusted downward during simulations until the model fits the observed growth (Stewart et al., **1983).** Since the physical volume of the stomach limits the maximum instantaneous meal size a fish can ingest, it represents the ultimate upper bound of the physiological maximum--given a knowledge of temperature-specific digestion rates. Thus, the relation of maximum stomach volume to fish size provides a simplified way to estimate the maximum possible daily consumption of a fish species.

Methods used to estimate maximum fish stomach capacity and to relate stomach capacity to fish size can be categorized as

direct or indirect. Maximum physical volume has been directly measured by inflating fish stomachs to the bursting point (Kariya et al., 1968), or filling stomachs with known volumes of water (Kimball & Helm, **1971;** Jobling et al., 1977; Flowerdew & Grove, **1979).** Indirect methods, which incorporate the behavior and physiology of fish, include laboratory studies of feeding to satiation (Magnuson, **1969)** and inferences based on maximum feeding observed in nature (Hellawell, **1971, 1972;** Knight & Margraf, **1982).**

    The purpose of this paper is threefold: First, to describe a new direct method of measuring maximum stomach or digestive tract capacity of fish by using air injection and water displacement, and to compare it with previous methods. Second, to test the technique on two piscivorous species of fish, one having a true stomach, coho salmon, <u>Oncorhynchus kisutch</u> (Walbaum); and one having a modified foregut (which functions as a stomach), northern squawfish, <u>Ptychooheilus</u> <u>oregonensis</u> (Richardson). Finally, we compare the species-specific functional relation between maximum volumes of the digestive organ (stomach, total digestive tract or foregut) to fish weight.

II. METHODS AND MATERIALS

FISH COLLECTION

Northern squawfish **(500**-**1500** g) **were** collected from the McNary Dam tailrace on the Columbia River (USA) during July **1987** using an electrofishing boat. The fish taken were transferred alive to the laboratory and maintained on a diet of juvenile salmon in tanks at 17.0 C, for digestive tract volume analysis in September. Coho salmon (300-3800 g) were collected and stomachs immediately dissected in October **1987** during spawning at the Little White Salmon National Fish Hatchery.   Each fish was weighed to the nearest gram, and fork length measured to the nearest millimeter.

APPARATUS

The volume displacement chamber, which had a working volume of 6.7 1 (Fig. 1), was constructed from a polyvinyl chloride pipe (10 x 91 cm). A 5 x 38 cm section was removed and a section of plexiglass, 0.32 cm thick was sealed in place with silicon sealer to form a viewing window. The base was threaded for easy removal and to facilitate cleaning. A 0.64 cm nozzle and plastic tube, located 2.5 cm from the top of the chamber, was used to transfer the displaced water to a graduated cylinder of appropriate size for accurate measurement.

Temperature inside the chamber was monitored with a digital thermometer. A constant temperature of **17.0** c was maintained by changing the water after each measurement, by opening the valve near the bottom of the chamber. The chamber was attached to a ring stand with ring clamps. A standard compressed gas cylinder (8.0 m^3) with an Airco*8400 two stage regulator having a guage with increments of **0.1** PSI (0.007 kg $\cdot cm^{-2}$), delivered air at a constant pressure. The air passed through a 0.64 cm plastic tube and nozzle that attached to the anterior end of the digestive organ with a hose clamp. The posterior end of the gut was sealed with a wire twist-tie. A bend was formed in the air tube and a lead weight was attached at the apex to hold the inflated digestive tract and hose under water.

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* The mention of a product name does not constitute endorsement by the U.S. Government.

Fig. **1.** Volume measurement apparatus (A), with insert showing attachment of northern squawfish digestive tract (B). Components: **(1)** volume displacement chamber, (2) viewing window, (3) base cap, (4) outflow nozzle, (5) outflow tube, (6) graduated cylinder, (7) drain pipe, (8) valve, (9) ring stand, (10) ring clamps, (11) gas cylinder, **(12)** pressure gauge, (13) air hose, (14) air nozzle, (15) hose clamp, (16) twist tie, and (17) weight.

A

B

17
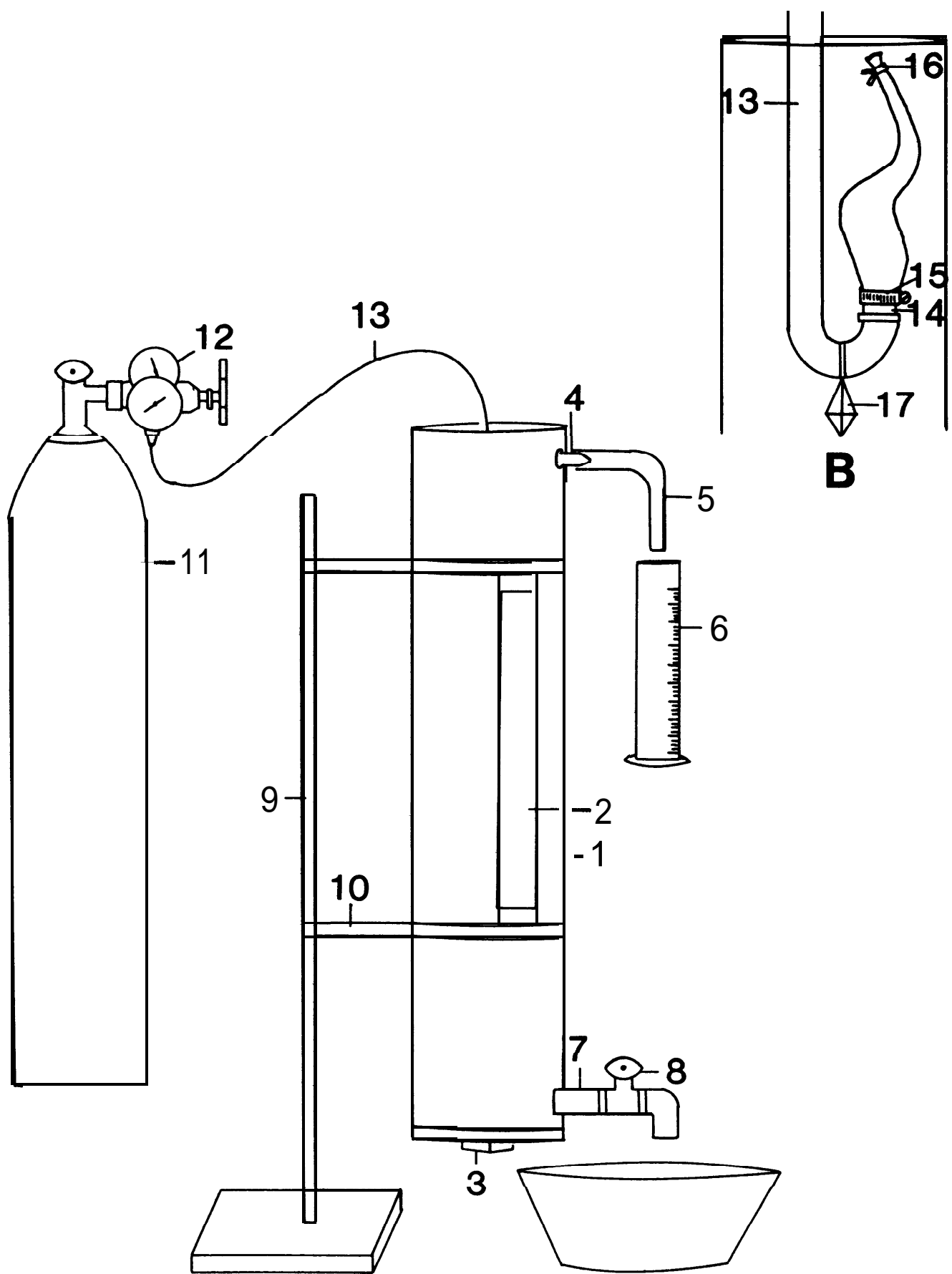
The chamber was constructed to facilitate the measurement of squawfish digestive tracts that were up to 515 mm in length and 137 ml in volume. A chamber of smaller diameter was used when the volume of the digestive organ was less than 20 ml, to facilitate a more accurate measurement.

DIGESTIVE TRACT MEASUREMENT PROCEDURE

The digestive tract from each northern squawfish, and the stomach from each coho salmon were removed (Fig. 2). Northern squawfish digestive tracts were dissected anteriorly at the back of the mouth and posteriorly at the vent. Because of the unique gastrointestinal morphology of northern squawfish (Weisel, 1962), we were careful to leave the cystic duct intact when the gall bladder was removed; otherwise, a natural orifice in the wall of the foregut resulted in large air leaks. Coho salmon stomachs were dissected at the back of the mouth and posteriorly at the front of the pyloric ceca. Each digestive organ was flushed with water, placed in a labeled plastic bag and kept on ice for 24 h until the volume measurement were made. Before measurement the digestive organs were acclimated in a bucket, containing water at **17.0** c. A volume measurement to the nearest milliliter was made for coho salmon stomachs or northern squawfish total digestive tracts and foreguts. Each digestive organ was attached at the anterior end to the air nozzle. Residual air was forced out of the organ and the posterior end was sealed with a twist-tie. The digestive organ was placed in the chamber and the water level stabilized to the bottom of the outflow spout. Pressure was gradually increased until the digestive organ was determined by visual inspection to be fully distended. Distention was considered complete when the digestive organ walls were evenly taut along the natural contours of the organ. Pressure was measured on the regulator gauge and recorded for each fish. Air leakage from the digestive organ was monitored through the viewing window. The amount of leakage was judged by applying a subjective scale: (0) none, (1) small, (2) moderate, and (3) large. Volume measurements corresponding to digestive organs with large air leaks were omitted from the analysis. The burst pressure was then measured for comparison with inflation pressure by increasing the pressure until the digestive organ ruptured, and the corresponding pressure was recorded.

Paired measurements of body-volumes to body-weights were made for a sample of 72 northern squawfish to ascertain the quantitative relation. Volume was determined by using water displacement in a **13.5** 1 chamber.

Fig. 2. Northern squawfish digestive tract, and coho salmon stomach; l= anterior cut, 2= posterior cut, 3= gall bladder cut, 4= foregut-hindgut cut. Abbreviations: GB= gall bladder, CD= cystic duct, and PC= pyloric ceca.

Northern squawfish digestive tract

A

Coho salmon stomach

B
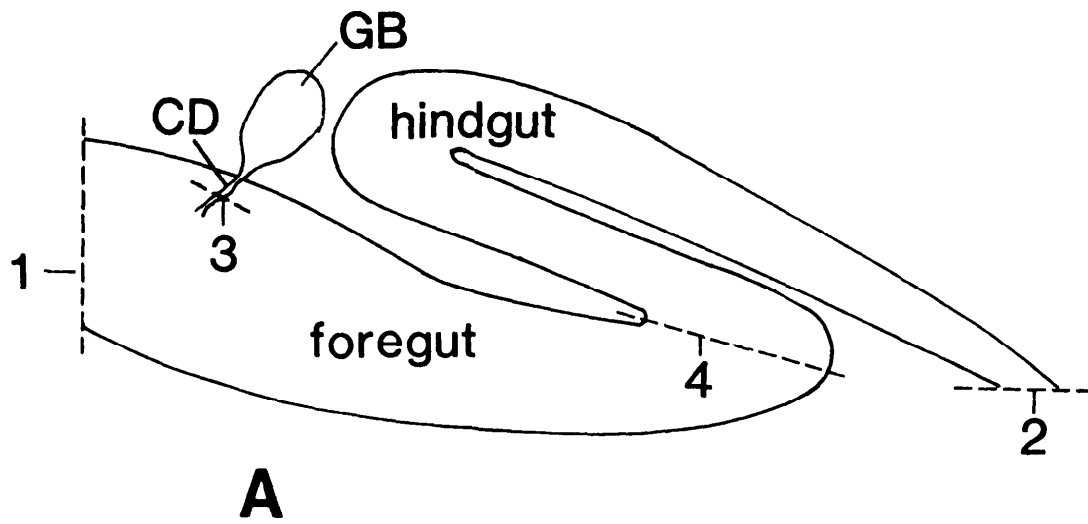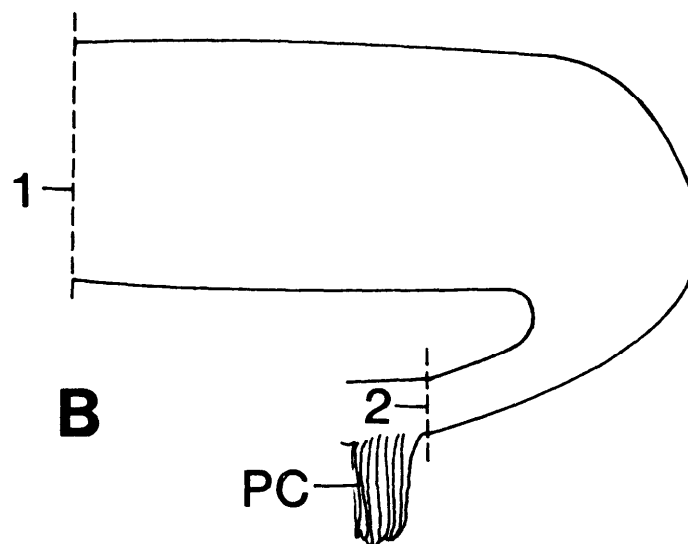
DATA ANALYSIS

Relations between fish weight (W) and stomach, total digestive tract, and foregut volume (V) were quantified by using least squares linear regression techniques. The data were fitted to three models: (1) linear, $V = a + b W$; (2) exponential, $V = e^{(a + b W)}$; and (3) multiplicative or allometric $V = aW^b$. Selection of the "best" model was based on the highest proportion of variability in digestive organ volume explained by fish weight (R^2), and inspection of the pattern of the residuals and their variability.

III. RESULTS

Nearly half of the digestive organs tested for volume determinations were rejected due to rips, ruptures or large air leaks (43% of coho salmon stomachs and 46% of northern squawfish digestive tracts). Of the intact structures, mean pressure required to fully inflate coho salmon stomachs **(0.123** kg **.** cm **$^{-2}$)** was significantly greater **(p<0.001)** than that required for the total digestive tracts **(0.097** kg **.** cm **$^{-2}$)** or foreguts **(0.058** kg **.** cm -2) of northern squawfish (Table I). Inflation pressure was not significantly related to either fish size or digestive organ volume (R2<= **0.10)** --thus indicating that mean inflation pressure of each digestive organ adequately represented the entire range of fish sizes. There was no significant difference (p> 0.10) between mean burst pressure of coho salmon stomachs **(0.214** kg **.** cm-2) northern squawfish total digestive tracts (0.308 kg **.** cms2, or foreguts **(0.280** kg **.** cm^{-2})**.**

Data from individual fish fitted to three regression models (Table II) indicated that the multiplicative model best described the relation between coho salmon body weight and stomach volume (R^2 **= 0.85),** whereas the exponential model best described the relation for northern squawfish total digestive tract (R2 = 0.55), and foregut **(R^2** = 0.61). Maximum digestive organ volume, averaged over 500-g body weight intervals for coho salmon and 100-g intervals for northern squawfish, were regressed on mean fish weight to illustrate the differences in the digestive organ capacity relations of the two species (Fig. 3).

Northern squawfish body weight (grams) was essentially equivalent to body volume (milliliters). There was a direct linear relation between fish weight (FW, g) and fish volume (FV, ml) with an intercept of zero, and slope near one: FV = 0.95 FW (n = **72,** R^2 = 0.98).

Table I. Mean inflation and burst pressures (kg $\cdot cm^{-2}$) for coho salmon stomachs, northern squawfish total digestive tracts and foreguts; measurements of digestive organs with large air leaks were omitted.

Species and digestive organ	Pressure (kg' cm^{-2})					
	Inflation			Burst		
	Mean	SD	Sample Size	Mean	Sd	Sample Size
Coho salmon						
Stomach	0.123	0.039	(24)	**0.214**	**0.059**	**(18)**
Northern squawfish						
Total digestive tract	**0.097**	**0.015**	(45)	**0.308**	**0.062**	**(10)**
Foregut	0.058	0.010	(30)	0.280	0.113	(21)

Table II. Regression models of coho salmon stomachs (n= 24) and northern squawfish total digestive tracts and foreguts (n= 32) on fish weight.

Species	Model *	Coefficients Intercept (a)	Coefficients Slope (b)	R^2	Residual Standard Error
Coho Salmon					
	Linear	-3.2345	0.0153	0.56	14.690
	Exponential	1.1537	0.0009	0.70	0.623
	Multiplicative	0.0007	1.3796	0.85	0.444
Northern Squawfish					
Total digestive tract					
	Linear	-6.3116	0.0652	0.48	20.836
	Exponential	2.8540	0.0012	0.55	0.308
	Multiplicative	0.0434	1.0380	0.54	0.312
Foregut					
	Linear	-8.1261	0.0416	0.53	12.078
	Exponential	2.1365	0.0013	0.61	0.305
	Multiplicative	0.0105	1.1603	0.59	0.313

* Linear: $V = a + b W$
  Exponential: $V = e^{(a + b W)}$
  Multiplicative: $V = a W^b$

Fig. 3. Models of maximum digestive organ mean volume, by weight interval, as a function of mean fish body weight for northern squawfish total digestive tract (0), foregut (0), and coho salmon stomach ([]).

Northern Squawfish Digestive Tract
$V = e^{(2.7822 + 0.0012W)}$
$R^2 = 0.90$

Northern Squawfish Foregut
$V = e^{(2.1219 + 0.0014W)}$
$R^2 = 0.87$

Coho Salmon Stomach
$V = 0.0012W^{1.2991}$
$R^2 = 0.89$

DIGESTIVE TRACT – STOMACH VOLUME (ml)

FISH WEIGHT (g)
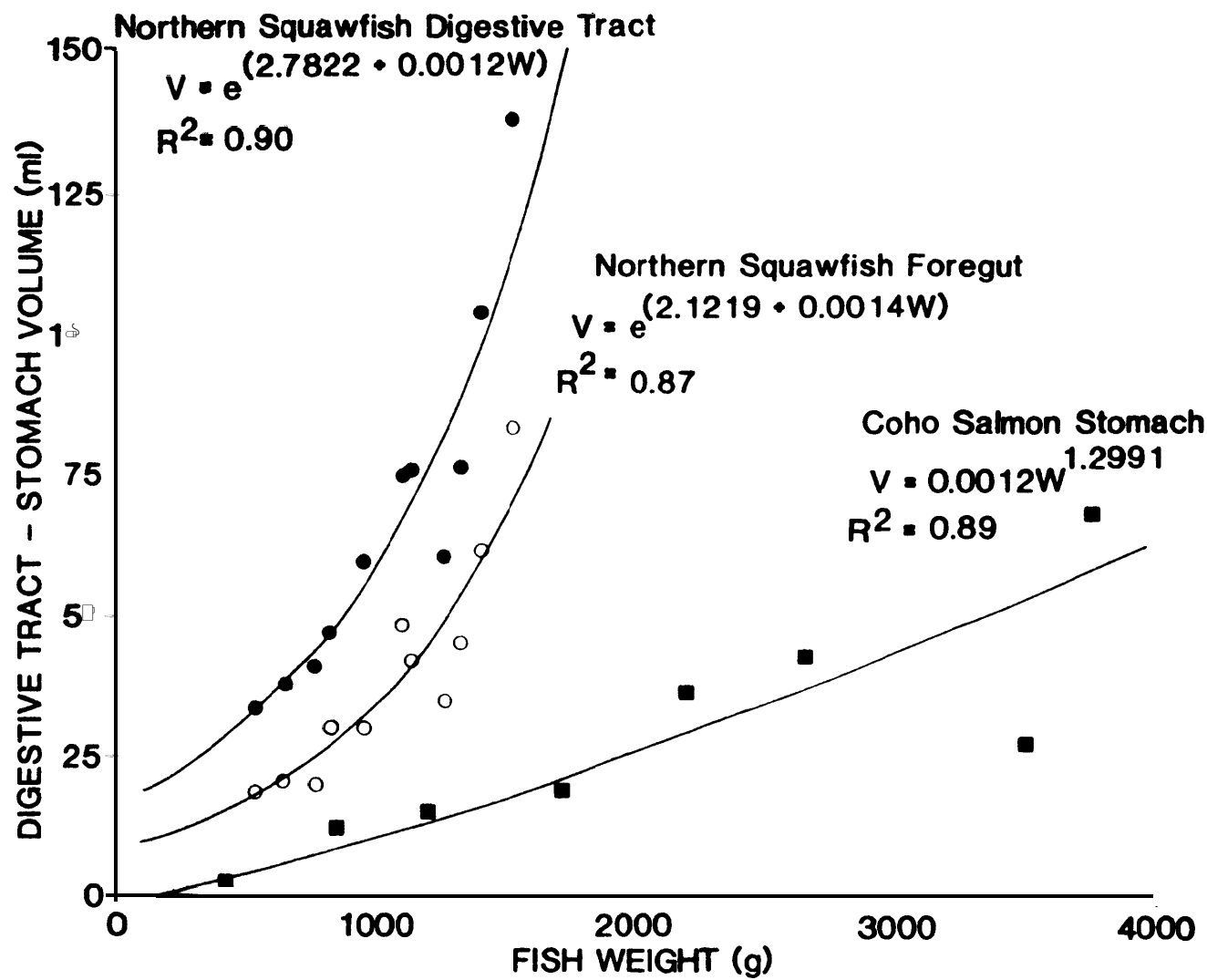
IV. DISCUSSION

TEST DATA

Mean inflation pressure of the digestive organs can be used as an objective end point when making maximum capacity determinations. For northern squawfish, the low amount of variability, as indicated by the coefficient of variation (total digestive tract, **15.5%**; foregut, **17.2%)**, showed that the subjective end point was constant. For coho salmon however, the mean inflation pressure was more variable (CV = 31.7%). This variability may have been due to either **(1)** differences in stomach elasticity caused by atrophy of the stomachs associated with different freshwater residence times, or (2) the subjective end point of stomach distention for coho salmon occurred over a wider range of pressure because the walls of the stomach were thicker than those of the northern squawfish digestive tract. In future studies, trial tests for a given species could establish a mean inflation pressure of a sample of fish digestive organs, which could then be used as an objective end point for later determinations.

Models of northern squawfish total digestive tract and foregut volumes as a function of fish weight were nearly parallel, indicating that the foregut composed a consistent proportion of the total digestive tract over the entire size range. Volume of the northern squawfish digestive tract and foregut increased at a faster rate per unit of body weight than did the stomach volume of coho salmon. This indicates that northern squawfish would be capable of consuming a higher instantaneous food ration than coho salmon and may reflect differences in digestive tract morphology of the two species. Coho salmon have a true stomach--i.e. a discrete food storage structure that is delimited posteriorly by a pyloric sphincter and contains gastric glands. In contrast, northern squawfish have a modified foregut--i.e. a swelling at the anterior portion of the intestine that functions to store and digest food, but lacks gastric glands and pyloric sphincter (Weisel, 1962). The differences in observed digestive organ capacity might also be partly explained by the two different feeding histories. When tested, the northern squawfish had been actively feeding in the laboratory. In contrast, the coho salmon were presumed not to have been feeding before the tests because (based on estimates of migration rates) the population that we sampled had been in the Columbia River for 20 to 40 days before we collected our samples. It is generally believed that Pacific salmon cease feeding when they enter fresh water, and that the stomach is reduced by autolysis when they reach the spawning grounds (Lagler et al., 1977). Thus coho salmon sampled in the open ocean may have a different relation between stomach volume and fish weight.

DIRECT VERSUS INDIRECT METHODS

The distinction must be made between direct measurement of the maximum physical capacity of the digestive organ and the indirect measurement of the physiological maximum capacity. Magnuson (1969) fed starved laboratory fish known volumes of food until satiation; total food volume ingested was plotted against fish body length and a regression line fitted above the data cluster to represent maximum values. Using starved fish, however, can give erroneous results; e.g. the stomachs of fish starved for **10** days appeared shriveled and had a lower volume:fish weight ratio than that of stomachs in freshly captured (actively feeding) fish (Flowerdew & Grove, **1979).** Stomach content volume from field collections has been plotted against fish length by using logarithmic coordinates (Hellawell, **1971, 1972);** a line subjectively fitted along the upper edge of the cluster of points was interpreted as the normal volume of a full stomach. Knight & Margraf **(1982)** also regressed stomach contents volumes on fish length, but assumed that the fish with the largest volume of stomach contents represented maximum stomach capacity for a size group. This method requires large sample sizes per size group, is sensitive to outliers, and masks variability of individual fish stomach capacity; data should be stratified by season to account for changes in feeding habits and physiology. Indirect methods have the advantage of incorporating the physiology and behavior of fish, thus being more readily interpreted biologically; however the effects of environmental conditions must be considered. Direct measurement of digestive organ volume provides a valid measure of maximum physical size of a stomach or digestive tract and is faster and less expensive than estimates using indirect methods.

COMPARISON WITH OTHER DIRECT MEASUREMENT METHODS

The new method has several advantages over other direct methods. Our method of inflating the digestive organ under water is an objective way of maintaining constant pressure and distention, as well as facilitating the detection of leaks in the digestive organ that could go undetected if a water injection method is used (Kimball & Helm, **1971;** Jobling et al., **1977).** The use of inflation pressure is more appropriate than burst pressure used by Kauriya et al. (1968); we found that mean burst pressure for coho salmon was about twice and for northern squawfish about four times that of corresponding inflation pressures--indicating that the amount of distention resulting in burst pressure would not he representative of normal stomach volume. Our method can be used to measure a wide range of shapes and sizes of digestive organs; in contrast the method of Kauriya et al. **(1968)** is limited

to digestive organ morphologies that can be inflated using a thin rubber sac attached to a glass tube and inserted into the stomach. The use of a rubber sac would be limited to digestive organs of a spherical shape; e.g. it would not work on northern squawfish digestive tracts. The process of dissecting the digestive organ from a freshly killed fish and placing it on ice rather than freezing it (Jobling et al., **1977)** also gives a more accurate measure of maximum volume. Flowerdew & Grove **(1979)** found that stomachs from deep-frozen fish showed a higher ratio of volume to fish weight and ruptured more easily than did stomachs from freshly killed fish.

Several workers have used fish length as the variable to predict digestive organ capacity (e.g. Magnuson, 1969; Kimball & Helm, 1971; Margraf & Knight, **1982).** For most species, fish weight is more appropriate because it is essentially equal to fish volume; therefore, stomach volume is being related to fish volume. A well documented allometric relation exists between fish length and weight; thus comparison of digestive organ volume to fish weight, eliminates the confounding effects of non-linearity relations in fish length.

One disadvantage of our method compared with other direct methods is that it is relatively time consuming and requires expensive equipment. Also, the handling of digestive organs during dissection and attachment to the apparatus, as well as inherent weaknesses in the walls of the organs, can result in ruptures in a large portion of the tracts--thus reducing the sample size. In addition the capacity for expansion of a dissected digestive tract, removed from surrounding organs, may differ from that of the intact structure in a living fish.

In summary, our method of using air inflation with water displacement worked well on two species of fish having digestive organs of different morphologies. We found that in northern squawfish, total digestive tract and foregut volume to fish weight were parallel and increased at a faster rate than did coho salmon stomach volume to fish weight. The apparatus should be scaled to an optimum size for a given fish species, considering the size of the digestive organ and accuracy of the measurement. The physical maximum digestive organ capacity differs from the biological maximum capacity, which incorporates physiological and behavioral considerations; a researcher needs to determine which is more appropriate for his specific applications. Feeding history, health of the fish, environmental regime and methods of preserving fish samples are variables that would affect volume measurements and should be considered when determining maximum digestive organ volume. Although previous methods might be more suitable in some instances, our method has three main advantages: it uses an objective measure of constant inflation pressure, enables easy detection of leaks in the digestive organ, and is useful on digestive organs having a wide range of morphologies.

Acknowledgements

References

Bajkov, A.D. **(1935).** How **to estimate** the daily food consumption of fish under natural conditions. Trans. Am. Fish. Soc. 65. 288-289.

Flowerdew, M.W. & Grove, D.J. (1979). **Some** observations of the effects of body weight, temperature, meal size and quality of gastric emptying time in the turbot, Scophthalmus maximus (L.) using radiography. J. Fish Biol. **14, 229-238.**

Hellawell, J.M. **(1971).** The autecology of chub, Squalis cephalus **(L.)** of the River Lugg and Afon Llynfi. III. Diet and feeding habits. Freshwater Biol. **1, 369-387**

Hellawell, J.M. (1972). The growth, reproduction and food of the roach Rutilus rutilus (L.), of the River Lugg, Herefordshire. J. Fish Biol. **4, 469-486.**

Hyslop, E.J. **(1980).** Stomach contents analysis--a review of methods and their application. J. Fish Biol. **17, 411-429.**

Jobling, M., Gwyther, D. & Grove, D. J. **(1977).** **Some** effects of temperature, meal size and body weight on gastric evacuation time in the dab Limanda limanda (L). J. Fish Biol. **10, 291-298.**

Kariya, T., Shirahata, S. & Nakamura, Y. **(1968).** An experiment to estimate the satiation rate of feeding in fish. Bull. Jpn. Soc. Sci. Fish. 34, 29-35.

Kimball, D.C. & Helm, W.T. **(1971).** A method of estimating fish stomach capacity. Trans. Am. Fish. Soc. **100,** 572-575.

Knight, R.L. & Margraf, F.J. **(1982).** Estimating stomach fullness in fishes. N. Am. J. Fish. Manage. 2, 413-414.

Lagler, K.F., Bardach, J.E. Miller, R.R. & Passino, D.R.M. (1977). Ichthyology. 2nd Edition. New York, London & Sydney: John Wiley & Sons, Inc.

Magnuson, J.J. (1969). Digestion and food consumption by skipjack
     tuna (Katsuwonus pelamis). Trans. Am. Fish. Soc. 98, 379-392.

Sainsbury, K.J. (1986). Estimation of food consumption from
     field observations of fish feeding cycles. J. Fish Biol. 29,
     23-36.

Stewart, D.J. & Binkowski, F.P. (1986). Dynamics of consumption
     and food conversion by Lake Michigan alewives: an energetics-
     modeling synthesis. Trans. Am. Fish. Soc. **115, 643-661.**

Stewart, D.J., Weininger, D., Rottiers, D.V. & Edsall, T.A.(1983).
     An energetics model for lake trout, Salvelinus namaycush:
     application to the Lake Michigan population. Can. J. Fish.
     Aquat. Sci. **40, 681-698.**

Thorpe, J.E. **(1977).** Daily ration of adult perch, Perca
     fluviatilis L. during summer in Loch Leven, Scotland. J.
     Fish Biol. **11, 55-68.**

Weisel, G.F. **(1962).** Comparative study of the digestive tract
     of a sucker Catostomus catostomus, and a predacious minnow,
     Ptychocheilus oregonense. Am. Midl. Nat. 68, 334-346.

Windell, J.T. (9978). Estimating food consumption rate of fish
     populations. In Methods for assessment of fish production
     in fresh waters. 3rd Edition(T.B. Bagenal, ed.), pp. **227-254.**
     Oxford: Blackwell Scientific Publications.

Use of diagnostic bones to identify and estimate
original lengths of ingested prey fishes.

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<u>Abstract</u> - We examined and measured cleithra, dentaries, opercles, and pharyngeal arches -- bones found to persist during digestion of most prey fish -to identify 24 prey fish species and back calculate their original fork length. Eighteen of the 24 species examined could be easily distinguished, however, for certain congenerics identification was neither consistent nor reliable for all bones within the size ranges examined. Relations between bone length and fish length were linear for 14 species for which the sample size was adequate (N > 30); coefficients of determination (r2) ranged from 0.79 to 0.99. Diagnostic characteristics and measurements of these bones provided reliable identification of genera and species and estimates of original fork lengths of partly digested prey fish from three predators. This method, compared with that of examining only prey fish in a measureable condition, greatly increased the amount of dietary information available from gut analysis.

Introduction

Emphasis in the analysis of fish diets has moved away from purely descriptive studies toward the integration of food consumption rates into metabolic energetics models. When one estimates consumption rates of piscivorous fishes, several factors must be determined, including predator size and the identity, number, and original size of prey fish. Information about prey consumed must often be reconstructed from fragmentary parts. Even when the digestive process is advanced, the slower digestion of bony material and the constant relation between bone length and fish size enable reliable identification and size reconstruction for most fish.

Bones have often been used by biologists to identify otherwise unidentifiable fish and to estimate fish length, and by archaeologists to reconstruct fish length and weight from remains found at archaeological sites (Casteel 1976). Bones have been used less frequently to estimate the original lengths of partly digested prey fish for feeding ecology studies (Pikhu and Pikhu 1970; Newsome **1977;** Mann and Beaumont 1980). Nevertheless, vertebral columns have been used to identify fresh and saltwater fishes and estimate prey lengths graphically (Clothier 1950; Crossman and Casselman 1969; Pikhu and Pikhu 1970); pharyngeal arches have been used in distinguishing catostomid and other fishes during stomach analysis (Eastman 1977; Mann and Beaumont 1980); lengths of the pharyngeal arch or opercle have been used to estimate prey length by use of linear regressions (Newsome **1977;** Mann and Beaumont **1980;** McIntyre and Ward **1986);** and pharyngeal arches, dentaries, and otoliths have been used by Eurasian biologists to estimate prey length (Popova 1967).

Our objectives are to describe the use of diagnostic characteristics of selected bones to identify prey fishes from predator stomachs and to estimate original prey size from measurements of selected bones. We describe the application of these procedures in retrieving information for the estimation of consumption and the description of the food habits of three piscivorous fishes in the Columbia River.

Methods

More than 700 fish less than 250 mm long (fork length) from 24 species (Table 1) were dissected to select diagnostic bones for identification purposes, and to determine the relations between the lengths of bones and fork length. The fish were collected in John Day Reservoir on the Columbia River or were obtained from fish hatcheries during spring and summer, 1984 - 1986. Specimens were immediately placed on ice until fork length (+ 1.0 mm) could be measured in the laboratory, and then frozen for further analysis. To remove bones, we thawed the fish and put them in boiling water for 30 to 60 s, depending on size, until the flesh could be easily removed from the intact skeleton. The bones were then preserved in 4% buffered formalin and stored in the laboratory until measured.

Identifying characteristics of cleithra, dentaries, opercles, and pharyngeal arches, were selected for examination from a subsample of 10 prey fish (or all available fish, if fewer than 10) over the size range collected. Unique characteristics of each of the bones were identified to distinguish fishes at the lowest possible taxonomic level in stomach contents of predators. Criteria for comparison included shape of each bone; length of the longest axis; pattern and lengths of processes, arms, and lobes; and number or arrangement of teeth in pharyngeal bones and dentaries.

Simple linear regression equations were calculated to estimate original fork lengths of 14 fishes from nine families for which the sample size of bones (N>30) was adequate. Fork lengths were regressed on measurements of the left bone. Bones less than 15 mm long were measured with an ocular micrometer at 8X power (+ 0.16 mm), and larger bones were measured with hand calipers (+ 0.05 mm) after blotting excess moisture. Cleithra were measured diagonally, from the anteroventral tip to the posterodorsal tip (Figure 1A). Dentaries of percopsids, centrarchids, and cottids were measured from the symphysis to the posterior edge of the fork that articulates with the angular bone (Figure 2A) and dentaries of clupeids from the symphysis to the posterior edge. Salmonid dentaries were measured from the symphysis to the posterodorsal notch on the dorsal limb. Opercles of cyprinids, catostomids, percopsids, and centrarchids were measured from the anterodorsal edge to the anteroventral margin (Figure 2B). Pharyngeal arches were measured from the dorsal tip to the ventral tip (Figure 2C).

We tested slopes of regression formulas by the F-test ($\underline{P}$ > 0.05) to determine if they were significantly different from zero. We also calculated confidence limits (95%) and percent error (confidence limit/ calculated length) through use of the shortest and longest bones in the sample to provide a measurement of error at the extreme ends of the data. We compared the total number of fish identified and sized from bones to the number of fish identified and measured by direct observations to

Table 1. Species, number (N), and length of potential prey fishes
          collected for examination from John Day Reservoir, **1983**-**1986.**

Family and species	Common name	N	Fork length (mm)
Clupeidae			
Alosa sapidissima	American shad	**46**	**39** - **98**
Salmonidae			
Oncorhynchus kisutch	Coho salmon	**50**	**89** - **132**
Oncorhynchus nerka	Sockeye salmon	**53**	**78** - **109**
Oncorhynchus tshawytscha	Chinook salmon	**53**	**42** - **184**
Prosopium williamsoni	Mountain whitefish	**9**	**66** - **177**
Salmo gairdneri	Steelhead trout	**46**	**93** - **210**
Catostomidae			
Catostomus columbianus	Bridgelip sucker	**52**	**89** - **250**
Catostomus macrocheilus	Largescale sucker	**58**	**61** - **229**
Cyprinidae			
Acrocheilus alutaceus	Chiselmouth	**52**	**98** - **242**
Cyprinus carpio	Common carp	**3**	**121** - **147**
Mylocheilus caurinus	Peamouth	**40**	**57** - **194**
Ptychocheilus oregonensis	Northern squawfish	**50**	**40** - **238**
Richardsonius balteatus	Redside shiner	**34**	**75** - **120**

Ictaluridae

Ictalurus nebulosus	Brown bullhead	4	**45** -	**56**
Ictalurus punctatus	Channel catfish	4	**109** -	**151**

Percopsidae

Percopsis transmontana	Sand roller	46	**30** -	**110**

Cetrarchidae

Lepomis gibbosus	Pumpkinseed	4	**67** -	**110**
Lepomis macrochirus	Bluegill	7	**94** -	**132**
Micropterus dolomieui	Smallmouth bass	36	**34** -	**95**
Micropterus salmoides	Largemouth bass	**5**	**120** -	**177**
Pomoxis annularis	White crappie	**17**	**35** -	**82**

Percidae

Perca flavescens	Yellow perch	**15**	**84** -	**169**
Stizostedion vitreum vitreum	Walleye	**13**	**154** -	**233**

Cottidae

Cottus asper	Prickly sculpin	49	**40** -	**137**

Figure 1. Lateral view of left cleithra of specimens representing
           nine families. A) Clupeidae, American shad; (B) Catostomidae,
           largescale sucker; (C) Ictaluridae, channel catfish; (D)
           Cottidae, prickly sculpin; (E) Cyprinidae, northern squawfish;
           (F) Salmonidae, chinook salmon; (G) Percopsidae, sand roller;
           (H) Centrarchidae, smallmouth bass; (I) Percidae, walleye.
           Abbreviations: cl = cleithrum length (measurement); ss =
           sickle-shaped process; vf = ventral fold; hl = horizontal limb;
           vl = vertical limb; ls = lateral shelf; sp = spine; dpl =
           dorsoposterior lobe. Scale bars: 2.0 mm.

Figure 2.   Representative dentary, opercle, and pharyngeal arch.
            (A) Left dentary of prickly sculpin; (B) Left opercle of
            smallmouth bass; (C) Left pharyngeal arch of northern
            squawfish (mesial view); (D) Left pharyngeal arch of
            northern squawfish (dorsolateral view). Abbreviations: dl =
            dorsal limb; dm = dentary measurement; fo = foramen; sy =
            symphysis; vl = ventral limb; fu = fulcrum; no = notch; om =
            opercle measurement; pr = primary ray; sr = secondary ray;
            pl = pharyngeal arch length (measurement); pt = primary
            teeth; st = secondary teeth; pw = pharyngeal arch width.
            Scale bars: 2.0 mm.

Figure 3.   Horizontal limb of left cleithra of cyprinids. Dorsal view of
            horizontal limb of (A) northern squawfish; (B) redside shiner;
            (C) peamouth; (D) common carp. Lateral view of horizontal limb
            of (E) northern squawfish; (F) chiselmouth. Abbreviations;
            ae = anterior edge of lateral shelf; ls = lateral shelf; mp =
            medial process; at = anterior tip of medial process. Scale
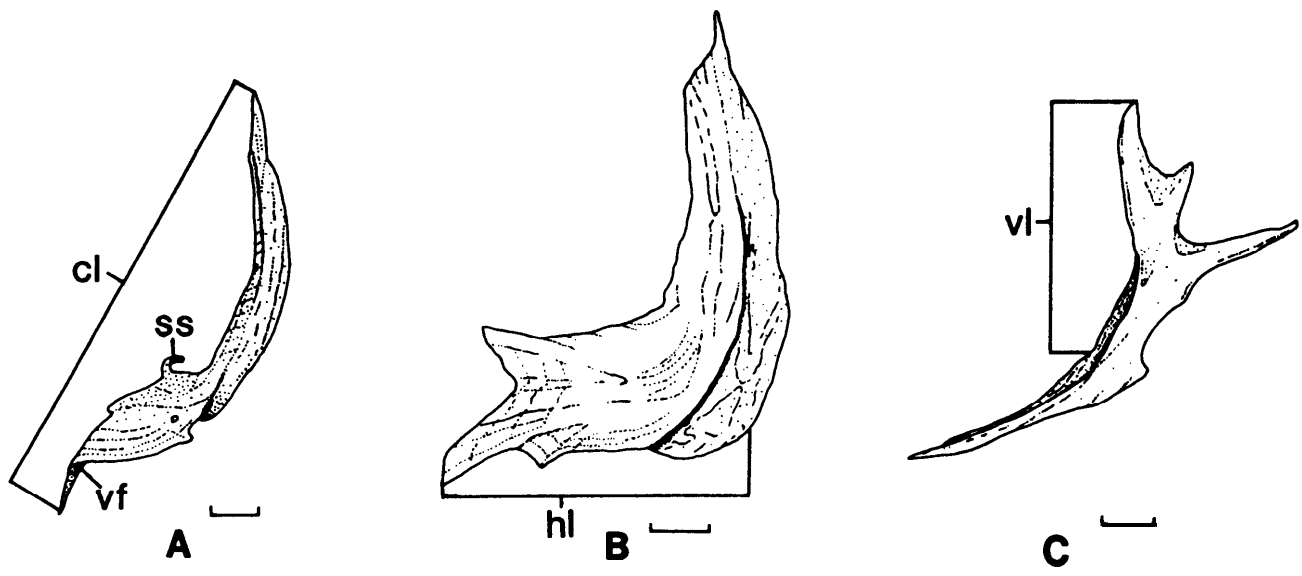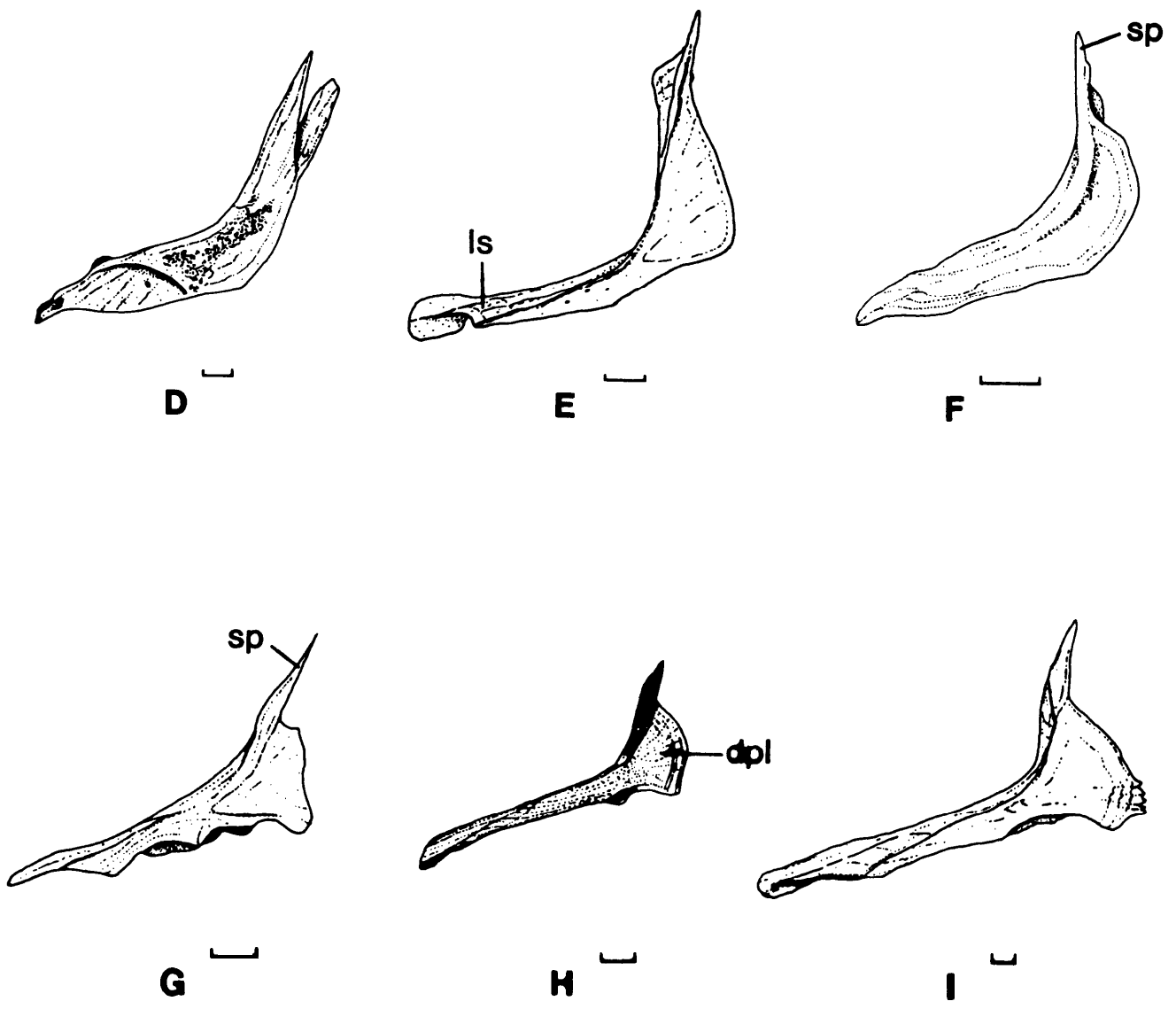   bars: 2.0 mm.
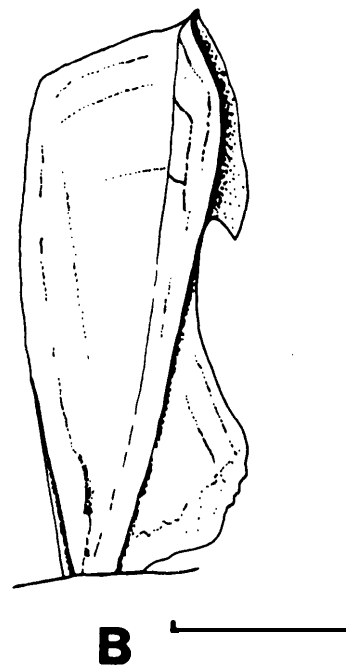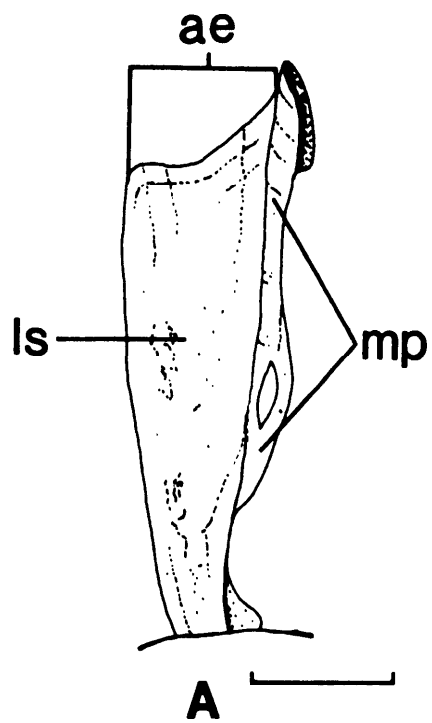
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Figure 2
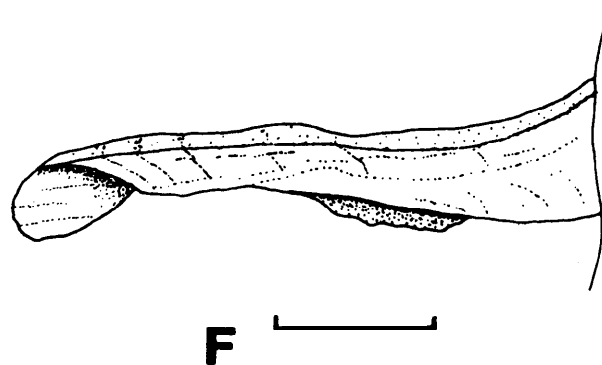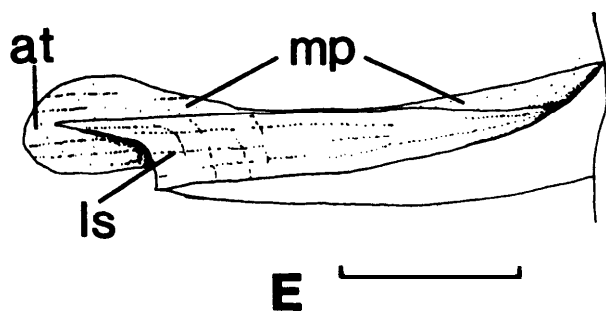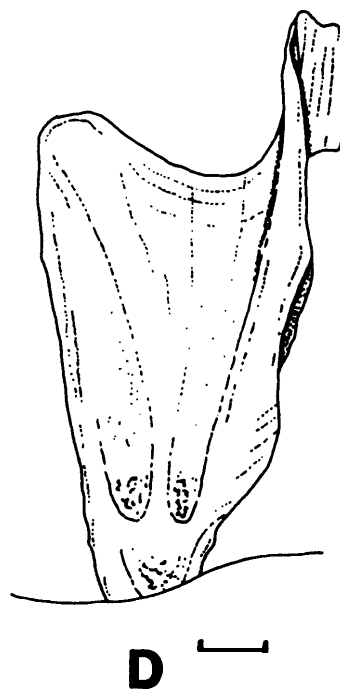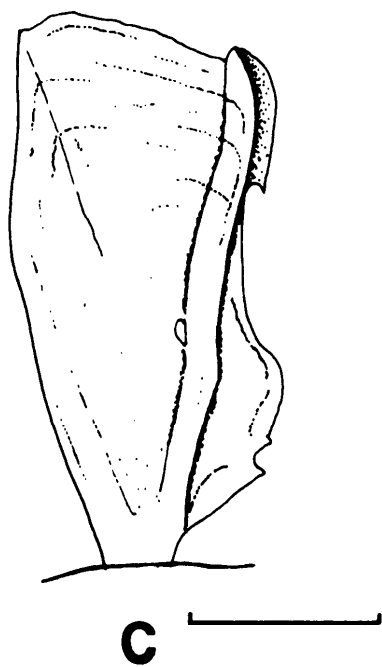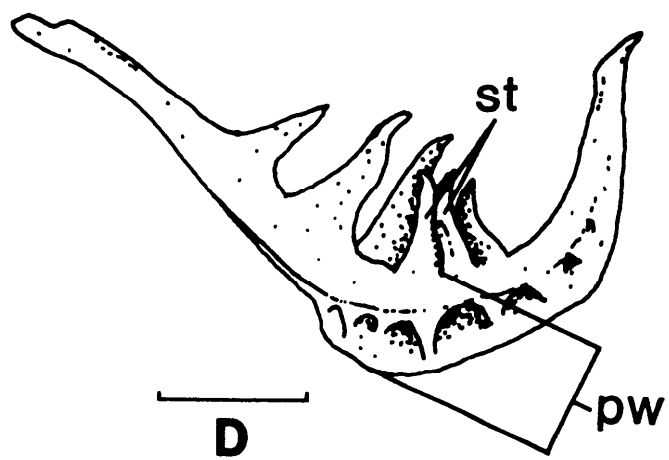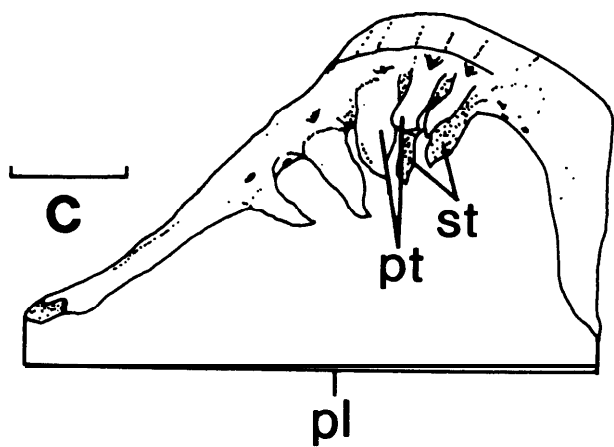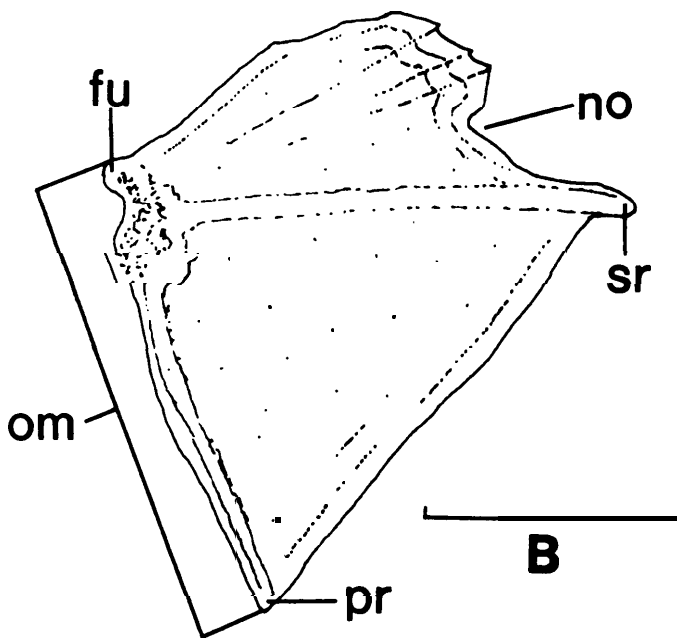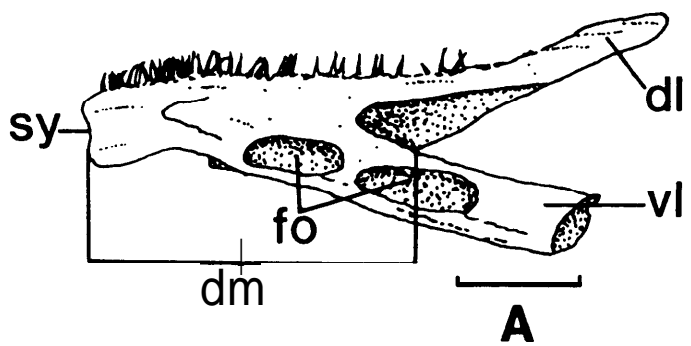
Figure 3

demonstrate how the information base may be enhanced through analysis of hard tissues.

Results

Identification of Prey Fish

Diagnostic characteristics of bones used to differentiate prey fish were found to be recognizable in the contents of predator stomachs. In general, resistance to digestion was greater in the larger, more robust bones used for identification, such as cleithra, opercles, dentaries and pharyngeal arches. Other bones were sometimes useful in identifying fish material (e.g., fused hypurals of the prickly sculpin and preopercles of the sand roller), but were often quickly digested, and rarely found wholly intact or in a measurable condition. Of the 24 species examined, 18 could be easily distinguished; however, for certain congenerics (Oncorhynchus; Catostomus; Lepomis; and Micropterus) identification was neither consistent nor reliable for all bones within the size ranges examined.

The cleithrum was diagnostic for all genera except those of the Salmonidae, in which steelhead could not be distinguished from the three salmon species. Other genera were separated on the basis of unique, characteristic shapes, and lengths or widths of particular features of the bone (Figure 1): in clupeids the cleithrum is fragile and has narrow limbs, a sickle-shaped process located medially, and a ventral fold (Figure 1A); in catostomids it has a horizontal limb terminating in three projections (Figure 1B); in ictalurids it has three projections on the vertical limb (Figure 1C); in cottids (prickly sculpin) it has forked vertical limbs (Figure 1D). In cyprinids, cleithra have horizontal limbs that terminate in an expanded lateral shelf (Figure 1E, 3), while in salmonids (Figure 1F) cleithra are crescent-shaped and expanded along most of both limbs. The cleithra of percopsids (sandroller), centrarchids, and percids are similarly shaped, having a narrow horizontal limb and a spine on the apex of the vertical limb (Figures 1 G,H, and I). The cleithrum of the sand roller can be distinguished from that of fish of the other families by its long spine and notched dorsoposterior lobe (Figure 1G). In centrarchids the cleithrum has a short spine and an unnotched, dorsoposterior lobe (Figure 1H), in percids it is notched along the dorsoposterior lobe (Figure 1I).

Genera within a family can also be distinguished on the basis of the cleithra. The cyprinids are an example of how genera can be differentiated. Cleithra of the cyprinid species are distinguished on the basis of the shape and angle of the lateral shelf of the horizontal limb (Figure 3). For example, the lateral shelf (horizontal plane or dorsal view) is slightly convex with slightly rounded corners in the redside shiner (Figure 3B); it is essentially straight, with the anterior

edge angling posteriorly in the peamouth (Figure 3C); and it is deeply emarginate in the common carp (Figure 3D). Cleithra of chiselmouth and northern squawfish are somewhat oblique at the anterior edge. The lateral shelf attaches at the middle of and is descendent to the medial process in northern squawfish, whereas it attaches near the top margin of the medial process in chiselmouth (Figures 3E, **3F)**.

Dentaries were diagnostic for all genera. They were rarely used for identification of cyprinids however, because the pharyngeal arches and cleithra were much more resistant to digestion and therefore recovered more frequently from stomachs. Dentaries were useful in distinguishing the three salmon species from steelhead; the dentary was wider and its ventral limb was relatively longer in the steelhead; than in the salmons. Other diagnostic characters of dentaries were the general shape, presence, and distribution of teeth (e.g., single row of canine teeth in steelhead versus a cardiform pad in species of Ictalurus); width of the symphysis; size and distribution of foramina; number of pores (in cyprinids); and the relative length of the dorsal and ventral limbs (Figure **2A)**.

Opercles, though diagnostic for all families and most genera, were less resistant than other bones to digestion. These bones differed among genera in general shape and surface of margins (smooth versus serrated), in the position of the primary and secondary rays (especially in centrarchids), and in the morphology of the fulcrum, spines, and notches (Figure 2B). The opercles of cyprinids could be distinguished from those of other families but were too similar to one another to permit differentiation of genera,

Pharyngeal arches with long, comb-like sets of teeth were diagnostic for the two species of Catostomus. Cyprinids were distinguished on the basis of the general shape of the arch and its relative width (Uyeno 1961), and on tooth formulae for the primary and secondary (and in carp, tertiary) rows of teeth (Figures 2C, 2D).

Estimates of Original Length of Prey Fish

Relations of bone length to fork length were linear and all had positive slopes that differed significantly from zero (F-test, P< 0.01). Regression models allowed estimates of fork lengths within $\pm$ 4 mm from bones retrieved from stomachs (Tables 2,3). From regression equations in which we used measurements of cleithra, dentaries, opercles, and pharyngeal arches of 14 species, we estimated mean fork length at the 95% confidence level with percent errors less than 9, 10, 6, and 5%, respectively, at the lower end of the length ranges, and less than 2% at the upper end of the length ranges. Coefficients of determination (r^2) ranged from 0.79 to **0.99;** for 75% of the regression equations,

Table 2. Regression statistics (Y = a + bX) relating measurements (in mm) of the cleithrum, dentary, or opercle (X) and fork length (Y) for 8 to 14 prey fish species from John Day Reservoir. Ranges of estimated fork length are also shown.

Species	N	Cleithra Coefficients a	b	Cleithra Estimated length (mm)	r^2	Dentary Coefficients a	b	Dentary Estimated length (mm)	r^2	Opercle Coefficients a	b	Opercle Estimated length (mm)	r^2
American shad	42	+ 3.94	5.67	33–87	0.98	+5.60	6.93	33–87	0.98	+ 7.22	7.99	35–98	0.98
Coho salmon	50	-17.05	9.71	46–166	0.96	+6.17	11.31	52–177	0.93	+ 9.57	12.15	53–160	0.93
Sockeye salmon	53	-14.79	9.39	76–112	0.91	-0.18	15.62	77–111	0.79	+16.01	11.25	79–144	0.91
Chinook salmon	53	-15.71	9.36	19–166	0.98	-12.11	13.05	18–166	0.98	+ 2.34	13.56	34–177	0.98
Steelhead trout	45	-16.70	10.27	90–201	0.97	+1.71	18.18	92–197	0.90	+ 4.44	15.64	92–192	0.94
Bridgelip sucker	52	-21.28	9.89	72-243	0.83	--	--	--	--	-20.90	12.56	76–241	0.94
Largescale sucker	58	+ 1.10	8.06	59-198	0.99	--	--	--	--	+ 0.15	10.65	56–197	0.99
Chiselmouth	52	-14.50	8.73	81–205	0.98	--	--	--	--	- 3.84	13.92	83–209	0.99
Peamouth	40	- 9.55	8.71	50–175	0.99	--	--	--	--	- 2.77	13.29	55-178	0.99
Northern squawfish	50	- 5.92	8.59	40–217	0.99	--	--	--	--	- 1.34	13.70	39–207	0.99
Redside shiner	33	+ 1.31	7.01	77–115	0.95	--	--	--	--	+ 4.26	10.93	76–115	0.92
Sand roller	46	+ 1.59	5.52	29–102	0.94	- 5.06	35.08	33–93	0.89	+ 2.62	10.09	29–106	0.93
Smallmouth bass	36	- 3.59	5.97	32–87	0.98	+7.42	12.59	31–88	0.97	- 4.86	11.20	34–89	0.98
Prickly sculpin	49	+ 5.08	5.47	41-134	0.99	+8.43	19.53	42-13	0.98	--	--	--	--

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Table 3. Regression statistics $(Y = \underline{a} + \underline{b}X)$ relating measurements (mm) of pharyngeal arch (X) and fork length (Y) for two species of Catostomidae and four species of Cyprinidae from John Day Reservoir. Ranges of estimated fork lengths are also shown.

| Taxon | N | Coefficients | | Estimated length (mm) | r^2 |
		a	b		
Catostomidae					
Bridgelip sucker	52	-25.61	17.73	81-242	0.86
Largescale sucker	58	-7.95	14.98	55-199	0.99
Cyprinidae					
Chiselmouth	52	-10.50	16.95	84-211	0.97
Peamouht	40	-1.84	14.70	51-180	0.98
N. squawfish	49	-1.05	13.24	38-209	0.99
Redside shiner	33	-1.37	14.33	77-117	0.86

coefficients were greater than or equal to 0.97.

Since we could not always distinguish between congeneric species by use of these bones, we used information on the relative abundance and geographic distribution of each species to aid in consumption estimates. For example, because large scale suckers contributed 92% of total suckers collected in the reservoir (Gray et al. 1985), we used the regressions developed for this species to estimate the original length of Catostomus spp. This procedure was followed for the other species within a genera such as Micropterus, Oncorhynchus, and Lepomis.

Estimates of prey fish consumption by three fish piscivores in John Day Reservoir on the Columbia River from 1983 to 1986 (Poe et al. 1986) entailed the collection and analysis of stomach contents of more than 11,000 fish (Table 4). The procedures for back calculation of original prey lengths from bones found in stomach samples resulted in a larger volume of information on consumption estimates, depending upon the predator species. Percentages of prey fish identifiable from only bone fragments ranged from about 38% for walleyes to 92% for northern squawfish, and averaged 72% for the three predators (Table 4).

Discussion

Unique characteristics of the four diagnostic bones selected for comparison and measurement facilitated identification of prey fish species collected during our study. After some familiarization with the bones, we found that even bone fragments could be used to identify prey fish during stomach analysis, although back calculation of original lengths was not possible. Unfortunately, however, it was difficult to differentiate between certain congeneric species. Comparison of bones from smaller specimens with those from larger fish did not indicate appreciable difference in bone shape or form.

Cleithra and dentaries were more persistent in the stomach contents of predators and served as the best means of identifying prey fishes. The cleithrum, because it is relatively large and is one of the first diagnostic bones to develop, was generally the most useful bone for identifying young-of-year fishes. We were able to identify small catostomids (<20 mm long) from the unique shape of the cleithrum. We found that the maintenance of a reference collection of bones of various sizes was useful, especially for identifying bone fragments.

The unique characteristics of pharyngeal arches have been well documented (Scott and Crossman 1973) and have been used for identification of cyprinid fishes whose opercles are easily digested and are therefore difficult to distinguish. Newsome (1977) encountered a similar problem in distinguishing each of the seven cyprinid prey fish he studied therefore, he used only the pharyngeal arches for identification.

Table 4. Number and percentage (%) of prey fish whose body lengths
were estimated or actually measured during stomach analysis of
three predator species collected in John Day Reservoir. The
lengths of ingested prey fish were estimated by use of either
diagnostic bone measurements or actual body length measurements
(data for 1983-1986).

| Predator | Total predator stomachs | Total prey fish | Prey body length | |
			Estimated	Actual
Northern squawfish	5467	2696	2480(92)	216(8)
Smallmouth bass	4940	2894	1887(65)	1007(35)
Walleye	1206	1095	419(38)	676(62)
Total N or (%)	11613	6685	4786(72)	1899(28)

Although the ability to estimate lengths of ingested fish on the basis of the dimensions of diagnostic bones varied among predator species, in our study the amount of information available from stomach analysis increased by **50%** to **1100%,** thus reducing the number of predators required in a sample to obtain a given number of prey items. The differences in the percentage of prey fishes identified from bones retrieved from different predators may have been due to differences in several factors, such as digestibility of fish versus non-fish items, the proportion of prey fishes ingested (e.g. adult walleyes are almost exclusively piscivorous in John Day Reservoir), digestion rates, or various combinations of these factors.

The linear relations of bone lengths to original body lengths observed in our study differed from those reported by Newsome **(1977);** the latter were curvilinear between opercle and body lengths for **10** prey fish species. However, our linear relations were consistent with those of Mann and Beaumont **(1980)** and McIntyre and Ward **(1986),** who estimated body lengths by use of pharyngeal arches. McIntyre and Ward **(1986)** found that length estimates of fathead minnow Pimephales promelas based on pharyngeal arches were more accurate than estimates of lengths of 10 prey fish species based on opercles, as judged by values of coefficients of determination (Newsome **1977).** In general, we obtained slightly more accurate estimates of fish length from measurements of the cleithrum and opercle than from measurements of pharyngeal arches or dentaries.

We found no instances in the literature of cleithra and dentaries being used to estimate the lengths of prey fishes found in the stomachs of piscivores. Scott **(1977),** however, used cleithra to estimate the length of Atlantic cod Gadus morhua found among remains recovered from a shipwreck and White (1936, **1953)** estimated lengths of fish by comparing measurements of maxillary, dentary, and parasphenoid bones found in regurgitated gizzard pellets of the belted kingfisher Ceryle alcyon with bones from specimens of known length.

Several limitations should be considered when using diagnostic bones to estimate original lengths of ingested prey fish. The length regression equations developed in this study were from measurements on bones subjected to the effects of preservative. We therefore recommend that, prior to use of these regression statistics, future investigators follow similar preservation procedures to avoid bias resulting from the potential effects of preservatives on fish bones. One should also be aware that use of diagnostic bones may bias food habits data by favoring larger over smaller prey fish because their bones may be more resistant to digestion.

Our results suggest that the identification and measurement of cleithra, dentaries, opercles, and pharyngeal arches of prey species provide an easy and reasonably accurate method of estimating original length of prey fish in partly digested remains. These methods may enable investigators to gain useful information that might otherwise be lost when prey fish length cannot be obtained by direct measurement.

Acknowledgments

References

Casteel, R. WQ. 1976. Fish remains in archaeology and paleoenvironmental studies. Academic Press, New York.

Clothier, C.R. 1950. A key to some southern California fishes based on vertebral characters. State of California, Department of Natural Resources, Division of Fish and Game, Bureau of Marine Fisheries. Fish Bulletin No. 79.

Crossman, R.J., and J.M. Casselman. 1969. Identification of northern pike and muskellunge from axial skeletons, scales, and epipleurals. Journal of the Fisheries Research Board of Canada 26: 175-178.

Eastman, J.T. 1977. The pharyngeal bones and teeth of catostomid fishes. American Midland Naturalist 97: 68-88.

Gray, G.A., D.E. Palmer, B.L. Hilton, P.J. Connolly, H.C. Hansel, and J.M. Beyer. 1985. Feeding activity, rate of consumption, daily ration, and prey selection of major predators in John Day Reservoir. Section I: Food consumption and prey abundance, 1984. Annual Report to Bonneville Power Administration by the U.S. Fish and Wildlife Service; Portland, Oregon.

Mann, R.H.K., and W.R.C. Beaumont. 1980. The collection, identification and reconstruction of lengths of fish prey from their remains in pike stomachs. Fisheries Management 11: 169-172.

McIntyre, D.B. and F.J. Ward. 1986. Estimating fork lengths of fathead minnows, Pimephales promelas, from measurement of pharyngeal arches. Canadian Journal of Fisheries and Aquatic Sciences 43: 1294-1297.

Newsome, G.E. 1977. Use of opercular bones to identify and estimate lengths of prey consumed by piscivores. Canadian Journal of Zoology 55: 733-736.

Poe, T.P., and nine co-authors, 1986. Feeding activity, rate of consumption, daily ration, and prey selection of major predators in John Day Reservoir, 1986. Annual Report to Bonneville Power Administration by the U.S. Fish and Wildlife Service; Portland, Oregon.

Pikhu, E.K.H., and E.R. Pikhu. 1970. Reconstruction of the sizes of fishes swallowed by predators from fragments of their vertebral column. Journal of Ichthyology (USSR) 10: 706-709.

Popova, O.A. 1967. The "predator-prey" relationships among fish. Pages 359-373 in Shelby D. Gerking, editor. The biological basis of freshwater fish production. John Wiley and Sons, New York.

Scott, J.S. **1977.** Back-calculated fish lengths and Hg and Zn levels from recent and **100** yr-old cleithrum bones from Atlantic cod (<u>Gadus morhua</u>). Journal of the Fisheries Research-Board of Canada **34:147-150.**

Scott, W.B., and E.J. Crossman. **1973.** Freshwater fishes of Canada. Bulletin **184,** Fisheries Research Board of Canada, Ottawa.

Uyeno, T. **1961.** Late Cenozoic cyprinid fishes from Idaho with notes on other fossil minnows in North America. Papers of the Michigan Academy of Sciences, Arts and Letters 46: **329-344.**

White, H.C. **1936.** Food of kingfishers and mergansers on the Margaree river, Nova Scotia. Journal of the Biological Board of Canada **2:299-309.**

White, H.C. **1953.** The eastern belted kingfisher in the Maritime Provinces, Bulletin **97,** Fisheries Research Board of Board of Canada, Ottawa.

Variation in Capture Efficiency of a Beach Seine for **Small** Fishes

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Abstract

     We tested the capture efficiency of a beach seine in an enclosed
area with the objective of improving our **estimates** of abundance of
small fishes of different taxa in littoral areas. Capture efficiency
for **14** taxa representing nine families was determined by seining
within an enclosure at night over fine and coarse substrates. Mean
efficiency ranged from **12** percent for prickly sculpin (Cottus **asper**)
captured over coarse substrates to 96 percent for peamouths
(Mylocheilus caurinus) captured over fine substrates. Mean seine
capture efficiency for a taxon was generally higher over fine
substrates than over coarse substrates, although mean capture
efficiencies over fine substrates were significantly greater for only
three of ten taxa. Capture efficiency generally was not influenced
by the number of fish available to the seine or by water temperature.
Seine catches adjusted to account for capture efficiency showed that
conclusions drawn from the apparent abundance in the catch and those
drawn from catches adjusted to account for capture efficiency differed
because taxa with low capture efficiencies became more important in
the adjusted catch.

Introduction

Beach seines are commonly used to assess the relative abundance of small fishes in littoral habitats, and periodic catches from the same location should provide useful information on population trends for a species. Because of differences in vulnerability to capture, however, conclusions regarding the abundance of each species captured in a seine haul cannot be drawn unless the capture efficiency (CE) of the seine used is known for each species captured. Capture efficiency has been defined as the number of fish captured divided by the number of fish actually present in the area sampled (Lyons 1986). If CE is known, the number of fish captured can be adjusted to improve the estimate of the number of fish actually present in the area sampled.

Seine CE is known to differ widely among fish species (Moav and Wolfarth 1970; Richkus 1980; Lyons 1986) and may differ within species for fish captured by different seining techniques or under different environmental conditions such as temperature, water clarity, and substrate type (Lyons 1986; Hunter and Wisby 1964). Differences in CE are caused by variations in the behavioral responses of fish, seining techniques, or physical conditions. In the few investigations of seine CE, variation related to differences in substrate has not been examined.

As part of a study to estimate the number of juvenile salmonids and other prey consumed by piscivorous predators in John Day Reservoir on the Columbia River, we wished to accurately estimate the abundance of prey-sized fish in littoral areas (Gray et al. 1985). We here describe how different substrates, number of fish available to the seine, and water temperatures influence seine CE and demonstrate how a knowledge of CE can be used to increase the accuracy of estimates of the abundance of fish present at the time of the sampling.

Methods

The CE of a beach seine was tested at four sites in the littoral
zone in John Day Reservoir, a 20,235 - hectare impoundment on the
Columbia River. The reservoir was created in **1968** when the United
States Army Corps of Engineers completed construction of John Day Dam
for hydroelectric power generation. The experiments, conducted from
April to August in **1985** and **1986,** consisted of **17** tests conducted
over fine substrates and **15** over coarse substrates at water
temperatures of $8°$ to $26°$ C. The fine substrates were composed of
sand (particle size $\leq$ 2 mm) and the coarse substrates were dominated
by cobble (particle size 64-250 mm), combined with smaller amounts of
gravel (particle size 2-64 mm) and sand.

Capture efficiency of the beach seine used (a bag seine 30.5 m
x 2.4 m made of 6.4 mm knotless nylon mesh) was determined by quadrant
seining at night within a square enclosure formed by using a block net
(92.5 m x 3.1 m, of 6.4-mm knotless nylon mesh) for three sides and the
shore for one side. The number of floats and leads per unit of length
in the block net was double that in the seine; floats and leads were
spaced 305 **mm** apart on the block net and **610** mm apart on the seine.
The enclosure was constructed during a period of about 20 min at
sunset, and seining began 10-30 min after the enclosure was completed.
Maximum depth within the enclosure never exceeded 2.4 m. The seine
was deployed perpendicular to the shore, along one side of the
enclosure. An extension rope was then used to haul the outside end
to shore. After 4 to **10** hauls were completed from alternate sides of
the enclosure, we hauled the block net into shore as a seine to
remove the remaining fish. Fish $\leq$ 250 **mm** fork length (FL) were
identified to the lowest taxon possible; larger fish were discarded
and fish < 30 **mm** FL were not counted, because we believed that **some**
of them could pass through the meshes of the seine and block net.

Seine capture efficiency (CE) for each taxon captured was
calculated by the equation:

$$CE = \frac{C}{T \times 0.64}$$

where C is the catch of fish of a given taxon in the first haul; T is
the total number of fish of that taxon removed from the enclosure;
and 0.64 is the ratio of the average area sampled by the seine on the
first haul to the area enclosed by the block net. Polar planimetry
was used to determine the average area sampled within the enclosure
in a single seine haul. The quantity T x 0.64, which estimates the

number of fish available to the seine on the first haul, was rounded
to the nearest integer. We assumed uniform distribution of fish
within the enclosure and did not calculate CE when T was <3. When
we caught more fish in the first haul than were estimated to be
available to the seine -- indicating a violation of our assumption of
uniform distribution and resulting in an estimate of CE > 1.0, CE was
said to equal one.

     Data collected in **1985** and **1986** were pooled for comparisons
among **taxa** and between substrate types. We required at least three
estimates of CE to yield a useful mean for each **taxon** for each
substrate. All estimates were normalized by an **arcsine**
transformation (**Zar** 1984). The statistical software package SPSS/PC$^+$
(SPSS Inc., **1983**) was used for all analyses. A t-test was used to test
the hypothesis that CE for a given **taxon** was equal (P > = 0.05) over
the fine and coarse substrates. If this hypothesis was not rejected at
the stated level of significance, a weighted mean CE was determined
by combining the data from both substrate types (**Zar 1984**).
Differences in seine CE among **taxa** for each substrate type were
assessed by one-way analysis of variance (ANOVA) and Newman-Keuls
multiple range tests. We used regression analysis to determine if the
number of fish available to the seine or water temperature caused
changes in CE.

     To demonstrate the effect of CE on catch composition of a beach
seine, we adjusted the catches in beach seine hauls that had been
conducted in other work. These extra seine hauls were made at night
with a seine identical to that used for the CE experiments. The
catch of each **taxon** was divided by the appropriate mean CE estimate
and rounded to the nearest integer. This provided an estimate of
actual abundance for that **taxon,** which could be compared to estimates
of actual abundance for other **taxa** captured.

Results

Mean CE estimates obtained for 14 taxa representing nine families ranged from **12%** for the prickly sculpin (Cottus asper) captured over coarse substrates to 96% for the peamouths (Mylocheilus caurinus) over fine substrates (Table 1). Generally, mean seine CE for a taxon was higher over fine substrates than over coarse substrates; it was significantly greater (t-test, $P < 0.05$) over fine substrates than over coarse substrates for chinook salmon (Oncorhynchus tshawytscha), suckers (Catostomus spp.) and prickly sculpin. Mean CE for crappies (Pomoxis spp.), however, was significantly greater over coarse substrates than over fine substrates (Table 1).

Mean CE did not differ significantly between substrates for chiselmouth (Acrocheilus alutaceus), northern squawfish (Ptychocheilus oregonensis), sand roller (Percopsis transmontana), sunfishes (Lepomis spp.), smallmouth bass (Micropterus dolomieui), or yellow perch (Perca flavescens). We therefore calculated a weighted mean CE for these taxa. Mean CE's for coarse substrates were not determined for four species -- American shad (Alosa sapidissima), peamouth, brown bullhead (Ictalurus nebulosus), and largemouth bass (Micropterus salmoides) --- because fewer than three estimates were obtained for these species over this substrate.

The results of our experiments indicated that mean CE differed significantly among taxa within each substrate type (ANOVA, $P < 0.05$); however, Newman-Keuls tests to determine where the differences occurred showed overlapping sets of similarities for all taxa over both substrate types.

Generally, the CE for a taxon was not influenced by the total number of fish of that taxon available to the seine or by water temperature. However, we found a significant relation between the number of brown bullheads available to the seine and CE ($r = $ **0.912**, $P < 0.05$) over fine substrates, and a highly significant though weak relation between water temperature and CE for suckers captured over fine substrates ($r = $ **0.681**, $P < 0.01$).

To demonstrate the effect of CE on estimated abundance we adjusted seine catches of fish collected from a backwater area of John Day Reservoir (Table 2) in **12** seine hauls (2 hauls over a fine substrate and 2 hauls over a coarse substrate each month in April, May, and June 1985). The catch of each taxon in each haul was divided by the appropriate CE estimate to provide an adjusted estimate of abundance for that taxon. Catches of fish from taxa with significantly different CE's for fine and coarse substrates were adjusted according to substrate

Table 1. Mean seine capture efficiency ($\overline{CE}$), 95% confidence intervals (in parentheses), and number of estimates (N) for prey taxa captured over fine and coarse substrates in John Day Reservoir, 1985 and 1986. The results are back-transformed from arcsine normalized data. Asterisks denote significant differences ($P<0.05$) in seine CE between the smooth and coarse substrates. Dashes indicate that insufficient data were collected to obtain a mean.

Taxon[a]	Age[b]	Fine substrate		Coarse substrate		Fine and coarse substrates weighted
		N	$\overline{CE}$	N	$\overline{CE}$	$\overline{CE}$
American shad	Y	6	0.34 (0.15 - 0.56)	—	—	—
Chinook salmon	Y, Y$^+$	9	0.84 (0.65 - 0.96)	11	0.55 (0.41 - 0.69)	*
Chiselmouth	Y, Y$^+$	4	0.91	11	0.72	0.78 (0.636 ⊢ 0.897) ⊢
Peamouth	Y, Y$^+$	12	0.96 (0.90 - 0.99)	—	—	
Northern squawfish	Y, Y$^+$	13	0.85	4	0.87	0.85 (0.76 ⊢ 0.93)
Suckers	Y, Y$^+$	16	0.78 (0.61 - 0.88)	14	0.45 (0.28 - 0.62)	*
Brown bullhead	Ym	6	0.33 (0.12 - 0.60)			—

Table **1. (con't).**

Taxon[a]	Age[b]	Fine substrate		Coarse substrate		Fine and coarse substrate weighted
		N	$\overline{\text{CE}}$	N	$\overline{\text{CE}}$	$\overline{\text{CE}}$
Sand roller	Y, Y$^+$	14	0. 42	6	0. 26	0. 37 (0. 23 - 0. 53)
Sunfishes	Ym	6	0. 56	3	0. 65	0. 59 (0. 36 - 0. 79)
Smallmouth bass	Ym	7	0. 56	5	0. 24	0. 42 (0. 21 - 0. 65)
Largemouth bass	Y	6	0. 40 (0. 24 - 0. 58)			
Crappies	Ym	6	0. 74 (0. 65 - 0. 83)	3	0. 90 (0. 61 - 1 .00)	*
Yellow perch	Y, Y$^+$	13	0. 47	4	0. 33	0. 44 (0. 26 - 0. 62)
Prickly sculpin	Y, Y$^+$	14	0. 28 (0. 16 - 0. 41)	15	0. 12 (0. 07 - 0. 18)	*

[a] Suckers = **largescale** sucker (Catostomus macrocheilus) and bridgelip sucker (C. columbianus);
sunfishes = bluegill (Lepomis macrochirus) and **pumpkinseed (L.** gibbosus); **crappies =** black
crappie (Pomoxis nigromaculatus) and white crappie (P. **annularis).**

[b] Y = young-of-the-year, Ym = mostly **young-of-the-year,** Y$^+$ = older than young-of-the-year.

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type. For example, the 39 chinook salmon captured over fine substrates were divided by 0.84 (the capture efficiency for chinook salmon over a fine substrate) and the **13** chinook salmon captured over coarse substrates were divided by 0.55 (the capture efficiency for chinook salmon over a coarse substrate). The combined estimated abundance of **71** chinook salmon in all hauls was 36% greater than the actual total catch of 52.

The estimated abundance of all **taxa** captured in these seine hauls increased after the catches were adjusted to account for CE (Table **2).** The estimated abundance for **taxa** with high **CE's** increased little, but estimated abundance increased substantially for **taxa** with low **CE's.** Roughly equal numbers were taken of the three most abundant **taxa:** yellow perch, 167; suckers, 155; and sand rollers, **148.** Catches of fish of each of the other **taxa** were less than 75. After catches were adjusted to account for seine CE, sand rollers and yellow perch remained the most abundant species, their estimated abundance being 402 and **381,** respectively. However, the adjusted estimated abundance of suckers (272) was less, and narrowly exceeded that of prickly sculpin **(246).** Mean **CE's** for other **taxa** captured were relatively high, and estimated abundances were less than 85 fish per **taxon.**

Table 2. Number of fish of each of nine **taxa** captured in 12 seine hauls, their estimated abundance, and percent change between total number captured and adjusted estimated abundance after the catch of a **taxon** was divided by the appropriate estimate of seine capture efficiency.

	Number of fish captured			Capture efficiency		Combined estimated abundance	
Taxon	Fine substrate	Coarse substrate	Total	Fine substrate	Coarse substrate	Number	Change in estimate (%)
Chinook salmon	39	13	52	0.84	0.55	71	37
Northern squawfish	29	10	39	0.85		46	18
Suckers[a]	82	73	155	0.76	0.45	272	76
Sand roller	117	33	150	0.37		402	168
Sunfishes[a]	6	30	36	0.56		61	69
Crappies[a]	22	46	68	0.74	0.90	82	17
Yellow perch	52	115	167	0.44		381	128
Prickly sculpin	47	9	56	0.28	0.12	246	339

[a] See footnote a, Table 1, for species.

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Discussion

Vulnerability to capture with a seine at night varied among taxa and was influenced by substrate type for some taxa. Differences in CE between species and, over different substrates within species may be due to variation in nocturnal behavior of different species -- including differences in distribution in the water column, foraging and resting behavior, and fright response. Emery (1973) and Helfman (1981) reported that many species of freshwater fish move inshore after dark and become inactive, often resting directly on the substrate; most species they observed could be approached closely (< 0.5 m) at night by a diver, and many could be touched before they darted away. This nocturnal torpidity in conjunction with fright response of torpid fish (a tendency to dart up from the substrate and away from the disturbance) and net avoidance behavior of active fish (Hunter and Wisby 1964; Leggett and Jones 1971) may result in increased vulnerability of certain taxa to capture in a seine. The preference of a fish for rocks as **cover** when it is either resting or frightened, or its ability to escape under the lead line, may also explain why CE differed among taxa and why it was for some taxa lower over coarse than over fine substrates.

The estimates of CE we obtained may have been overestimated because some fish undoubtedly avoided capture by both the seine and block net. However, we believe that the number of escapes from the enclosure were small because the areas were seined repeatedly, and the block net (with double the number of floats and leads that were on the seine) was retrieved through the sampling area. Our technique should not have impeded fish from avoiding capture by the seine; fish could escape under the lead line, over the float line, or around the outside end of the seine, just as during routine quadrant seining.

Generally, neither the number of fish of a taxon available to the seine nor water temperature influenced CE. However, the number of brown bullheads (mostly schooling young-of-the-year) available to the seine over smooth substrates was directly related to CE -- an indication that brown bullheads were more vulnerable to capture by **a** seine when in **a** school. A direct relation was also observed between water temperature and CE for suckers taken over fine substrates but not , over coarse substrates. Other taxa captured showed no such relation.

Hunter and Wisby (1964) reported that schooling common carp (<u>Cyprinus</u> <u>carpio</u>) avoided capture by a moving net en masse, and that common carp tested in a group were more successful in escaping a moving net than were those tested individually. They also noted that loose schools of common carp were better able to escape a moving net

at **24°** C than at **11°** C, but that the escape route dif fered. Common carp in the cooler water used a bottom escape route whereas those in warmer water used a top escape route. The suckers we captured over a smooth substrate may have used similar escape routes, making them more vulnerable to capture in warmer water.   The net avoidance experiments of Hunter and Wisby **(1964)** showed that common suckers (Catostomus canmersoni) tested at water temperatures of **13-16°C** rarely used the bottom escape route.

Seine CE may be influenced by size (or age) of fish captured, but not enough samples were collected in the present study to test for differences.   In as much as behavior of young-of-the-year fish has been shown to differ from that of older fish of the same species, it is likely that size of fish affects seine CE (Emery **1973;** Helfman **1981).**

Increase in estimated abundance was greater in taxa with low seine CE's than those with high CE's because CE and adjusted catch were inversely related.   Therefore, the overall effect that CE has on adjusted catches is more pronounced when the species complexes studied are composed of several taxa with different CE's.

The need for evaluating capture efficiency of a seine depends on the intended use of the data collected. If an accurate assessment is required of forage fish, as in our study of predator-prey interactions in John Day Reservoir , or in the abundance of juvenile fishes, an evaluation of capture ef ficfency is paramount. In evaluating capture efficiencies it is important that the seining experiments duplicate the techniques used and environmental conditions encountered when the data are collected to which the results are to be applied.

Acknowledgments

References

Emery, A.R. **1973.** Preliminary comparisons of day and night habits of freshwater fish in Ontario lakes. Journal of the Fisheries Research Board of Canada **30:761-774.**

Gray, G.A. D.E. Palmer, B.L. Hilton, P.J. Connolly, H.C. Hansel, J.M. Beyer, and G.M. Sonnevil. **1985.** Feeding activity, rate of consumption, daily ration, and prey selection of major predators in the John Day Pool. Annual Report to the Bonneville Power Administration. National Fishery Research Center, Cook, Washington, USA.

Helfman, G.S. **1981.** Twilight activities and temporal structure in a freshwater fish community. Canadian Journal of Fisheries and Aquatic Sciences **38:1405-1420.**

Hunter, J.R. and W.J. Wisby. **1964.** Net avoidance behavior of carp and other species of fish. Journal of the Fisheries Research Board of Canada **21:613-633.**

Leggett, W.C. and R.A. Jones. **1971.** Net avoidance behavior in American shad (Alosa sappidissima) as observed by ultrasonic tracking techniques. Journal of the Fisheries Research Board of Canada **28:1167-1171.**

Lyons, J. **1986.** Capture efficiency of a beach seine for seven fresh-water fishes in a north-temperate lake. North American Journal of Fisheries Management **6:288-289.**

Lyons, J. In press. **Distribution,** abundance, and mortality of **small** littoral-zone fishes in Sparkling Lake, Wisconsin. Environmental Biology of Fishes.

Moav, R., and W.G. Wohlfarth. **1970.** Genetic correlation between seine escapability and growth capacity in carp. Journal of Heredity **61:153-157.**

Richkus, W.A. **1980.** Problems in monitoring marine and estuarine fishes; Pages **83-118** in C.H. Hocutt and J.R. Stauffer, Jr., editors. Biological monitoring of fish. D.C. Heath, Lexington, Massachusetts.

SPSS Inc. **1983.** SPSS/PC+ for the IBM PC/XT/AT. SPSS Inc., Chicago.

Zar, J.H. **1984.** Biostatistical analysis (second edition). Prentice-Hall Inc., Englewood Cliffs, New Jersey.

Data Documentation

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COLUMBIA RIVER PREDATOR DIET ANALYSIS
COMPUTER PROGRAM

An IBM BASIC computer program was created to organize food habits, data files (see Table 1) and produce summaries according to various criteria determined by the operator in interactive mode.

The program was designed in eight interconnected modules:

(1) "START" selects the desired subprogram,
(2) **"FOODINPT"** creates stomach content data files and inputs data,
(3) "FOODED **IT"** corrects data files,
(4) **"FOODLIST"** lists each data record in a file,
(5) **"SMOLTLST"** summarizes consumption of juvenile salmonids,
(6) **"FOODSLCT"** (a) selects conditionals by which data are sorted and (b) loads processing and output modules,
(7) "FOODCALC" calculates summary statistics, and
(8) "FOODPRNT" prints out summary tables.

Using **"FOODSLCT"** food habits data was processed according to six criteria: predator species (northern squawfish, walleye, smallmouth bass, or channel catfish); predator size (minimum and maximum length); collection gear (electroshocker, bottom gill net, trawl, or combination); location (five major locations, each with several subareas, or a combination of locations); sample period (any interval between specified dates or entire year); time of day (any diel period within the 24-hour sampling regime).

The data set delimited by the selected conditionals is described with various statistics by "FOODCALC." These include sample size, number of stomachs with and without contents, mean predator size, organisms consumed, and total number and weight of food contents. Additionally, for each food item, the number of stomachs containing it (percent and frequency of occurrence), number of individual organisms (total, mean, and percent), weight of food item (total, mean, and percent), and the Index of Relative Importance are calculated. Although this program was designed specifically for Columbia River species composition and sampling stations, it could readily **be** modified for other applications. Thus, it may he useful to workers conducting food habits research at field stations equipped with minicomputers.

List of FWS data files (* . DAT = diet data files and * . CON = consumption data files) for all predator species and years sampled including sample size (n) and bytes per file.

Data	Files	n	No. Bytes
CHC	[1]/82	69	33, 327
CHC	83	189	91, 287
CHC	84	161	77, 763
CHC	85	176	85, 008
CHC	86	162	78, 246
SMB	[2]/82	941	454, 503
SMB	83	1, 063	513, 429
SMB	84	1, 246	601, 818
SMB	85	1, 676	809, 508
SMB	86	955	461, 265
SQF	[3]/82	1, 059	511, 497
SQF	83	1, 655	799, 365
SQF	84	1, 087	525, 021
SQF	85	1, 043	503, 769
SQF	86	1, 682	812, 406
WAL	[4]/82	253	122, 199
WAL	83	501	241, 983
WAL	84	339	163, 737
WAL	85	292	141, 036
WAL	86	74	35, 742

All Years Combined

CHC	8@	526	254, 058
SMB	8@	3, 985	1,924,755
SQF	8@	3, 785	1,828,155
WAL	8@	1, 132	546, 756

[1]/ CHC = channel catfish

[2]/ SMB = smallmouth bass

[3]/ SQF = northern squawfish

[4]/ WAL = walleye

COLUMBIA RIVER PREDATOR CONSUMPTION RATE COMPUTER PROGRAMS

Computer programs written in BASICA for IBM-PC compatible microcomputers were developed to estimate consumption from stomach contents data based on a technique originated by W.A. Swenson in **1972** (Ph.D. dissertation, University of Minnesota). This method synthesizes empirical diel samples of predators' diets with experimentally determined evacuation rates in order to estimate daily consumption rates of juvenile salmonids in terms of **(1)** grams of prey per average predator, (2) milligrams prey per gram of predator, and (3) number of prey per average predator. The product of the latter statistic and predator population size (estimated by ODFW) yields an absolute daily consumption estimate.

The consumption analysis is accomplished with two programs. The first program converts diet data files (including date, location, time of collection, predator weight, temperature, and the sample weight of each prey item) to a new file, having the additional variables necessary for consumption calculations: original preyfish length and weight, mass evacuated, percent digested, digestion time, and time of ingestion. Original preyfish lengths and weights are estimated from body length or bone measurements using species-specific regression equations. Mass evacuated and percent digestion are back-calculated from the difference in original and digested weights. Duration of digestion for each preyfish is estimated from evacuation rate regressions; time of ingestion can subsequently be back-calculated from time of collection. The second program performs the actual consumption calculation from grams of juvenile salmonids consumed per prey size, group and diel time period, and the numbers of potential predators in corresponding strata.

To date, separate programs have been written to estimate daily prey consumption by northern squawfish, walleye, smallmouth bass and channel catfish. All diet and consumption data files and program listings are stored on magnetic disks **(5-1/4"** IBM format) and copies are available at cost from the:

U.S. Fish and Wildlife Service
Columbia River Field Station
Star Route
Cook, WA 98605

SECTION II

Oregon Department of Fish and Wildlife
17330 S.E. Evelyn Street
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Project No. 82-12

Effects of Variation in Flow on Distributions of Northern
Squawfish in the Columbia River below McNary Dam

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Abstract

    The movements of northern squawfish (<u>Ptychochelius oregonensis</u>)
were monitored using radio-telemetry below a Columbia River
hydroelectric dam during the outmigration of juvenile anadromous
salmonids in 1984 and 1985. Northern squawfish were associated with
protected shoreline areas in spring and early summer when discharge
rates were high (above 5,664 m^3/sec) but moved into close proximity of
the dam and the juvenile by-pass outflow area in mid to late summer
when discharge rates decreased (below 5,664 m^3/sec). Similar trends in
northern squawfish movements were found when abrupt changes in
discharge occurred. Movements out of protected areas and into the main
river channel were observed in 4 out of 5 northern squawfish monitored
during short-term spill closures.

    Northern squawfish appeared to avoid high velocity (>100 cm/sec)
areas. Surface water velocity measurements taken at 81 locations where
northern squawfish occurred in June, July and August, 1985, ranged from
0 to 70 cm/sec with a mean of 24.5 cm/sec. These results suggest that
predation by northern squawfish at fish passage facilities may be
reduced by placing by-pass outflows in areas of high water velocity.

INTRODUCTION

Impoundments on rivers containing stocks of anadromous salmonids have necessitated the development of facilities to by-pass downstream migrant juvenile trout and salmon around the dams. One concern at these by-pass facilities is that conditions created by dams can concentrate predators by intensifying their foraging efficiency on juvenile salmonids. Sacramento squawfish were more abundant at Horseshoe Bend's fish release site than at control sites in the Peripheral Canal, California (Anonymous 1980). The by-pass facility at Red Bluff Diversion Dam, California, was found to induce stress on downstream migrants and attract predators which resulted in high mortality due to predation (Vogel and Smith, 1984). Gray et al. (1983) noted that the frequency of occurrence of salmonids in diets was higher for northern squawfish collected near mid-Columbia River dams than for those collected in other areas.

The objectives of this study were to: (1) describe the distribution of northern squawfish in McNary tailrace, (2) determine how different flow regimes affected the distribution of northern squawfish and (3) determine implications of predator distribution on the design of fish passage facilities.

STUDY AREA

McNary Dam is a hydroelectric facility located on the mid-Columbia River between Washington and Oregon (Fig. 1). The smolt by-pass outlet is situated in the center of the dam between the spillgates and turbines. Water discharge at McNary Dam varies with snow melt from the surrounding mountains of the Columbia Basin. Between March and mid-July, water discharge past McNary Dam may reach 11,400 m3/sec. Maximum turbine outflow at McNary is 5,664 m3/sec, hence all discharge in excess of this must be passed through the spillgates and fishways. By mid-July, runoff is substantially reduced and water is no longer spilled. Water discharge is stable from late summer through fall, and increases slowly throughout winter until the spring runoff surge requires spillgate operations.

The majority of juvenile salmon and steelhead pass McNary Dam between March and August. The highest numbers of outmigrants, however, are usually not found in the by-pass system until mid to late summer when discharge is reduced and the spillgates are closed. At this time the outmigrants attempt to pass primarily through the turbines.

Traveling screens in the turbine gatewells (Bates 1970) guide the
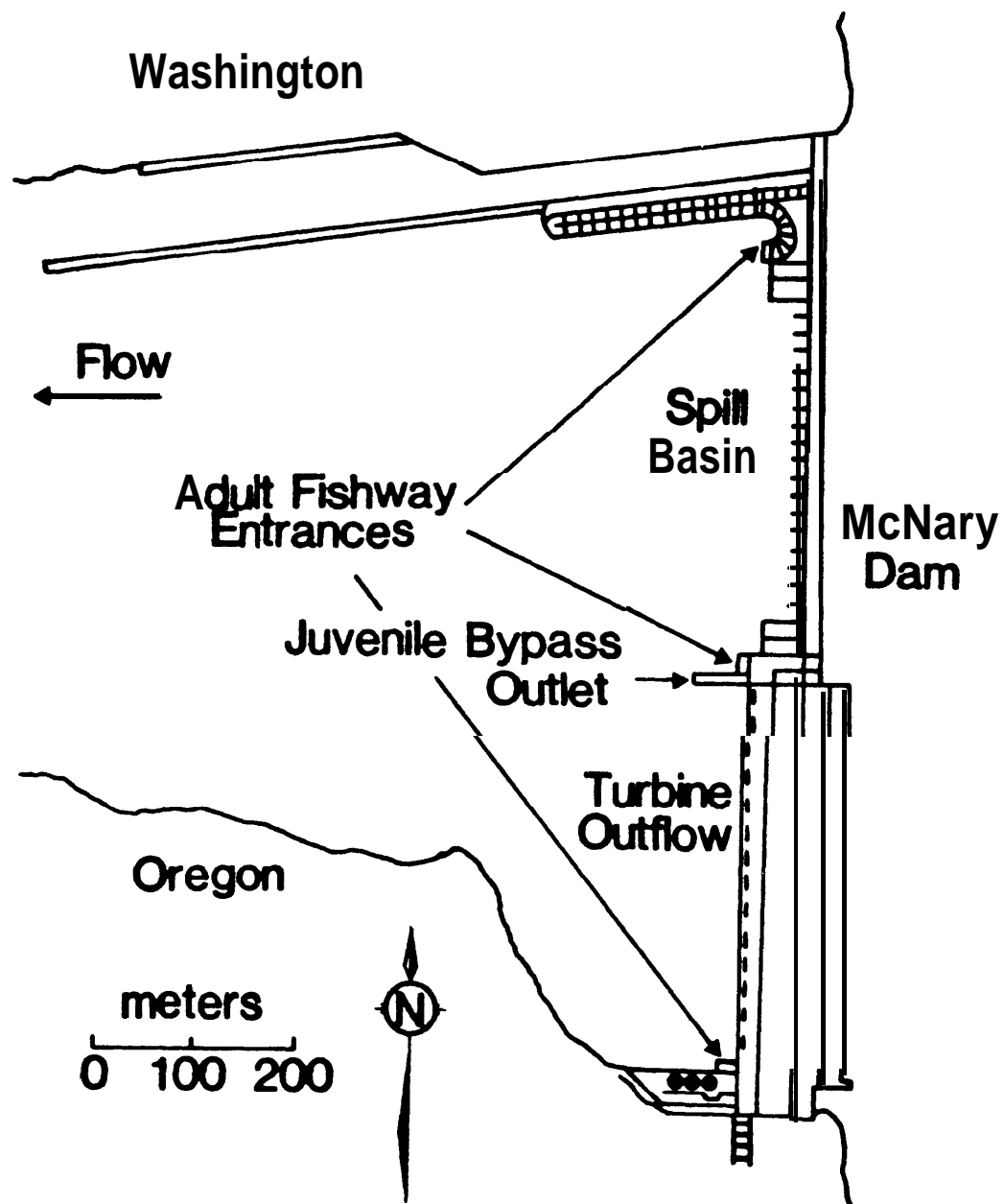
Figure 1. Locations of the juvenile bypass outlet, spill basin, turbine outflow, and fishway entrances at McNary Dam.

juveniles away from the turbines and into the by-pass system where the fish are subsampled, identified and enumerated. The juvenile salmonids are then either released through the by-pass outlet into McNary tailrace or transported by barge or truck to the Bonneville tailrace and released.

METHODS

The movements and distribution of northern squawfish in McNary tailrace were monitored using radio-telemetry equipment obtained from Advanced Telemetry Systems[1] of Bethel, Minnesota. ATS "Challenger 200" receivers were equipped with David Clark noise attenuatinq headsets, and were capable of scanning programmed frequencies between 48 and 50 mhz. Transmitters had a life expectancy of 150 days, weighed 28 g in air, were cylindrical and trailed a 35cm fine wire antenna from one end. Frequencies were separated by 10 kHz increments (Table 1) to allow for easy identification of individual fish and compensate for frequency drift when battery power declined.

Northern squawfish were collected by electrofishing in McNary tailrace (10 in March, **1984** and **13** in April and May, 1985) and surgically implanted with a radio-transmitter. Upon capture, fish were anesthetized in a 105 mg/liter solution of Tricaine-Methane-Sulfonate (MS-222). Each fish was weighed and measured (mm). (Table 1).

Surgical procedures were similar to those used by Hart and Summerfelt **(1975)** except an additional 0.5 cm incision was made in the abdominal cavity to allow for protrusion of a flexible wire antenna. The antenna exit hole was closed with a single suture. Sutured areas were swabbed with Betadine antiseptic, and the fish moved to fresh water for recovery. After the fish regained equilibrium and resumed swimming activity it was released at the point of capture.

Two antenna types were used to receive signals. Bidirectional loop antennas were affixed beneath the wing of an aircraft for aerial monitoring. Antennas were oriented with the peak receiving end directed forward. The unit was insulated from metal contact with the wing surface, and coaxial antenna wire was securely taped to the underwinq and led into the cabin through an air vent. Boat tracking was conducted from a **21** foot fiberqlass boat using a 4 element Yagi antenna (long range) attached to a telescoping **12** foot **mast** with 360° rotational capability. Hand held bidirectional loop antennas (short range) were also used in the boat and from shore. Once a signal was

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[1]Mention of commercial services or equipment does not constitute U.S. Government endorsement.

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Table **1.** Descriptive data on 23 northern squawfish radiotagged and
released in McNary tailrace, 1984 and **1985.**

Year	Transmitter Frequency (MHz)	Fork Length (mm)	Weight (g)	Date of Release
1984	48.184	470	1,450	3-14
	48.210	500	1,910	3-15
	48.334	517	1,625	3-15
	48.373	467	1,370	3-15
	48.412	480	1,400	3-15
	48.493	465	1,440	3-20
	48.551	495	1,620	3-20
	48.637	481	1,330	3-22
	48.657	447	1,375	3-27
	48.678	466	1,380	3-27
1985	48.184	460	1,475	4-10
	48.209	501	1,702	4-10
	48.333	505	2,185	4-10
	48.373	469	1,559	4-10
	48.414	479	1,502	4-14
	48.492	485	1,587	4-14
	48.553	445	1,530	4-14
	48.638	456	1,530	4-14
	48.658	474	1,587	4-14
	48.679	464	1,474	5-3
	49.598	453	1,531	6-4
	49.779	455	1,418	6-5
	*48.209	450	1,474	5-3

*Indicates transmitter was returned by an angler and subsequently
implanted in a second fish.

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received, the axis of maximum signal strength was followed. A reduction of the RF gain would take place until the observer was confident he had obtained an accurate location (fix).

The radio-tagged fish were monitored from aircraft, boat, and shoreline two to four times weekly from their time of release (Table 1) through August. Individual fixes were recorded in respect to distance and direction from known landmarks, and classified as either inshore (< 100m from a natural shoreline) or offshore (> 100m from a natural shoreline). Each fix was assigned an x and y coordinate from a Cartesian grid system (150 m/side) overlaid upon a U.S. Geological Survey map of the study area.

The movements of 5 northern squawfish were also monitored during short term spill closures in May, 1985 to determine how abrupt changes in water discharge may affect predator distributions. The fish were monitored at 5-10 minute intervals for 1-2 hours after the spill closures.

Surface water velocity measurements were taken with a Marsh-McBirney digital flowmeter at 63 randomly chosen locations in McNary tailrace during July and August, 1985 to map the tailrace flow regime. Individual measurements were triangulated to known landmarks with a Davis Mark IV sextant. Measurements were plotted on a U.S. Geological Survey map of the study area using a 3-arm protractor. Contour lines were drawn connecting points of similar surface water velocity.

Locations of radio-tagged northern squawfish were separated by time periods corresonding to mean daily discharge rates. Since preliminary results indicated that the presence or absence of spillgate discharge se ems to effect the distribution of predators in the tailrace, maximum possible turbine flow (5,664 m^3/sec) was chosen to delineate periods of high and low discharge (Fig. 2). Periods of high discharge were defined as those in which mean daily discharge rates exceeded 5,664 m^3/sec, and periods of low discharge refer to mean daily discharge rates < 5,664 m^3/sec. Distributions of the predators within high and low discharge periods were examined, and a chi-square analysis was used to compare inshore-offshore movements during these periods. It should be noted, however, that mean daily discharge rates in excess of the maximum possible turbine flow do not imply consistent spillgate operations due to navigation and fish passage needs, and water availability.

RESULTS AND DISCUSSION

In both 1984 and 1985 radio-tagged northern squawfish were usually distributed in small backwaters and protected shoreline areas during high water discharge (>5,664 m^3/sec) and spillgate operations (Fig. 3),
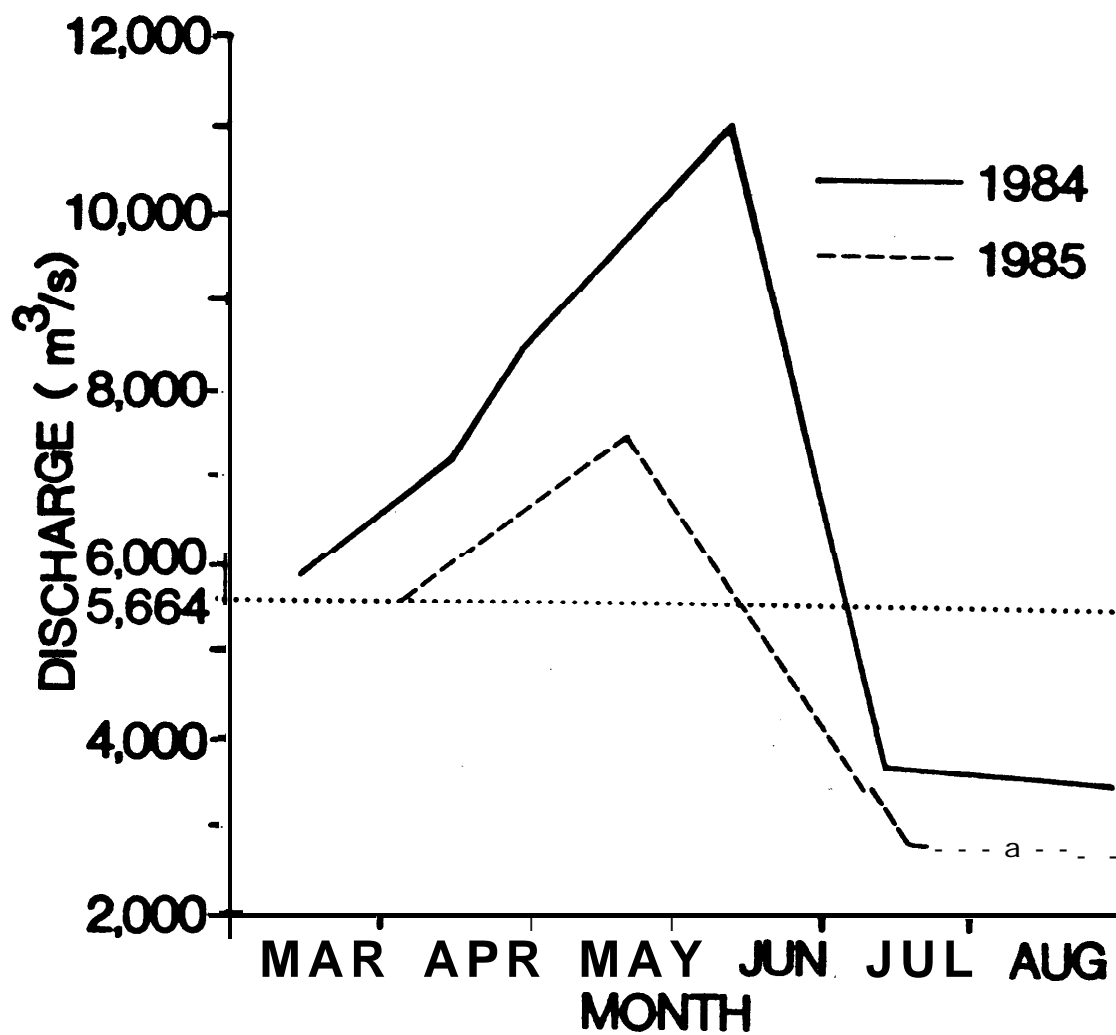
Figure 2. Mean daily discharge rates, illustrating time periods when
discharge exceeded maximum turbine outflow (5,664 m^3/s),
McNary Dam, March-August **1984** and 1985.

Figure 3. Distributions of radio-tagged northern squawfish during high discharge rates (>5,664 m³/s) in McNary tailrace, March 14 - July 18, 1984, and April 17 - June 20, 1985.

but moved into the main river channel and near the dam when discharge decreased ($\leq$5,664 m^3/sec) and spillgates were closed (Fig. 4). Chi-square analysis showed a significant difference (p < 0.01) between the frequency of inshore and offshore observations during high and low discharge rates in both **1984** and **1985** (Table 2). In spring and early summer when discharge was high, northern swuawfish were often located a considerable distance downstream from the dam. In **1984,** 7 northern squawfish (70%) were located farther than **2.5** km from McNary Dam. Locations from these fish outside the tailrace comprised **17.6%** of all observations taken in **1984;** 98.6% of these occurred when discharge exceeded 5,664 m^3/sec. Nine northern squawfish (75%) were located >2.5 km downstream from the dam in 1985. Again, this occurred primarily when discharge rates were high and spillgates were open. These locations comprised 38.6% of all observations in 1985, and 63.4% of these took place when discharge exceeded 5,664 m^3/sec. All 7 northern squawfish which left the tailrace in 1984, and 5 of the 9 which left in 1985 returned to <2.5 km from the dam by late July.

In mid to late summer when discharge was low, the predators were primarily distributed in the spill basin (Fig. **4).** During this period high concentrations of predator locations occurred near the smolt by-pass outflow and the Washington adult fishway entrance. Observations near the by-pass and fishway entrance comprised **70.4%** of all locations taken during low water discharge in **1984** and **31.3%** in **1985.** The occurrence of predators observed away from the dam during low water discharge was more common in **1985** than in **1984.**

Northern squawfish distributions seemed to be associated with the surface velocity regimes in the tailrace. Water velocity data from July and August, **1985** demonstrates a pattern typical of late summer when spillgates are consistently closed (Fig. 5). A large area immediately downstream from the turbine outflow and a **small** area immediately downstream from the Washington fishway entrance had velocities in excess of **100 cm/sec.** Velocities ranging from 50-00 cm/sec were observed bordering those areas in excess of **100 cm/sec.** The slowest water velocities in the tailrace were observed below the spill basin and along the Oregon shore downstream from the turbine outflow; velocities in these areas ranged from o-49 sm/sec. A comparison of northern squawfish distributions to the current velocity regime indicates that the predators prefer areas with slow water velocity or flow shears bordering high velocity areas.

In order to confirm this hypothesis we looked at surface velocity measurements at 81 northern squawfish locations taken in June, July and August, **1985** during the day, crepuscular and niqhtime hours. Individual velocity measurements at predator locations ranged from 0-70 cm/sec and averaged 24.2 **cm/sec.** Since a large proportion of the tailrace has velocities in excess of **70 cm/sec** we believe this data confirms the avoidance of high water velocities by northern squawfish. The data did not reveal any preference for specific velocities by the

Table 2. Frequency of inshore-offshore location at low $(\leq 5664 \text{ m}^3/\text{sec})$ and high $(\geq 5664 \text{ m}^3/\text{sec})$ discharge rates for radio-tagged northern squawfish in McNary tailrace, **1984 (n** = 346) and 1985 **(n** = 286).

Year	Discharge	Inshore	Offshore
1984	low	**66**	**41**
	high	**214**	**25**
1985	low	**110**	99
	high	**66**	**11**

1984

McNary Dam

1985

McNary Dam

number of
locations

▦ 1-5

▢ 6-10

▩ 11-20

■ > 20

kilometers

0   0.5   1.0

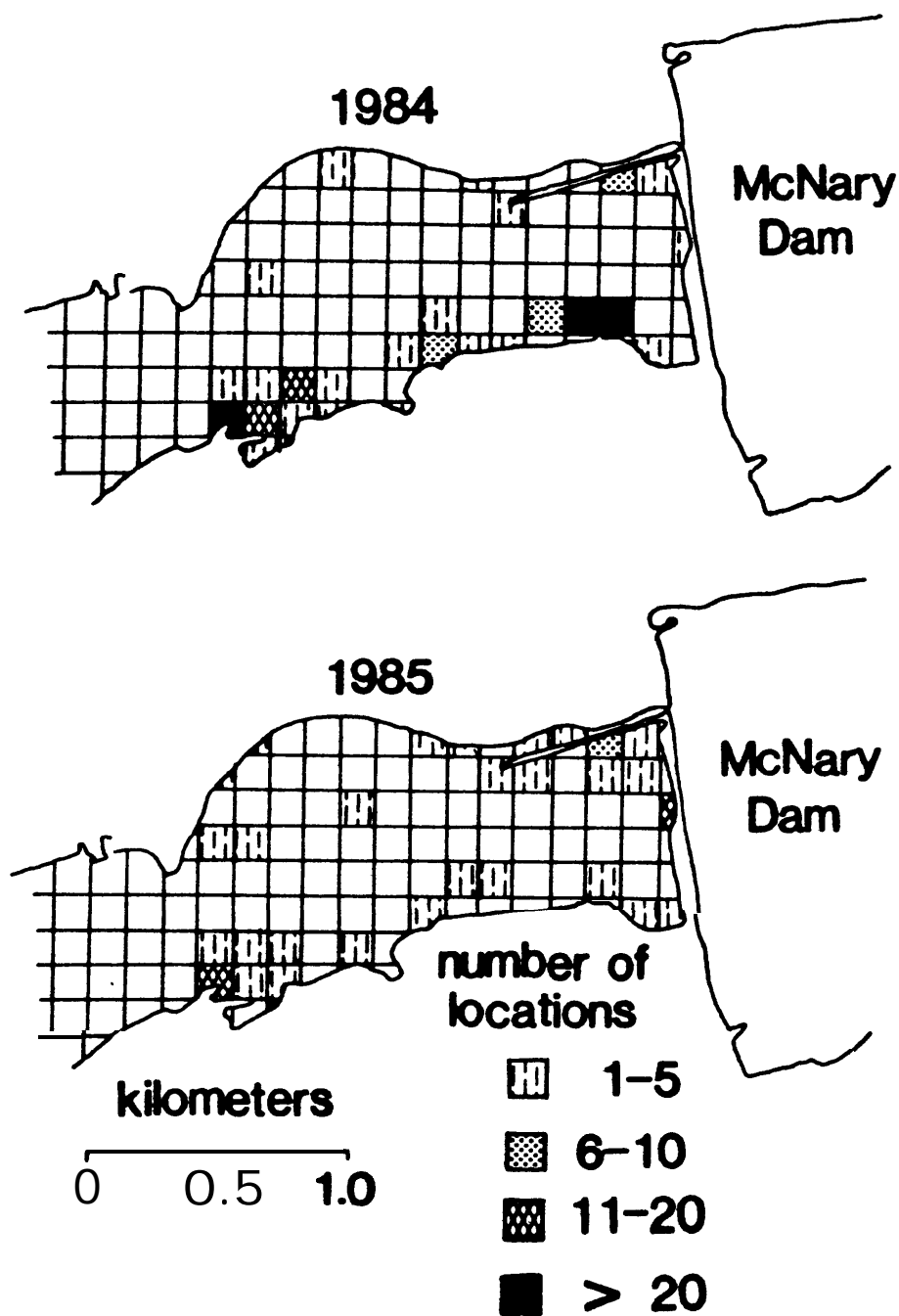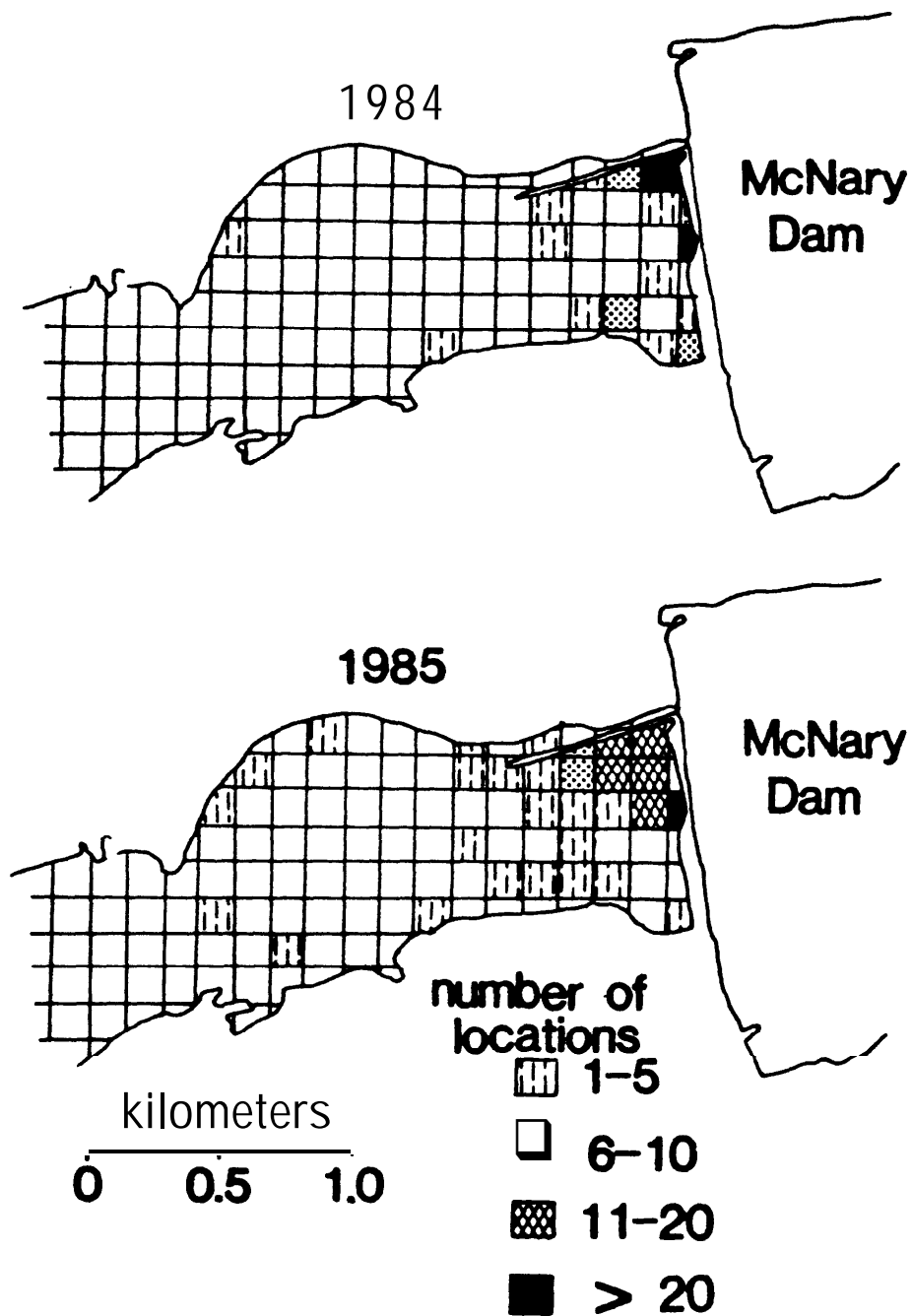Figure 4. Distributions of radio-tagged northern squawfish during low
discharge rates (<5,664 m^3/s) in McNary tailrace, July
19 - August **31,** **1984,** and June **21** - August 31, **1985.**
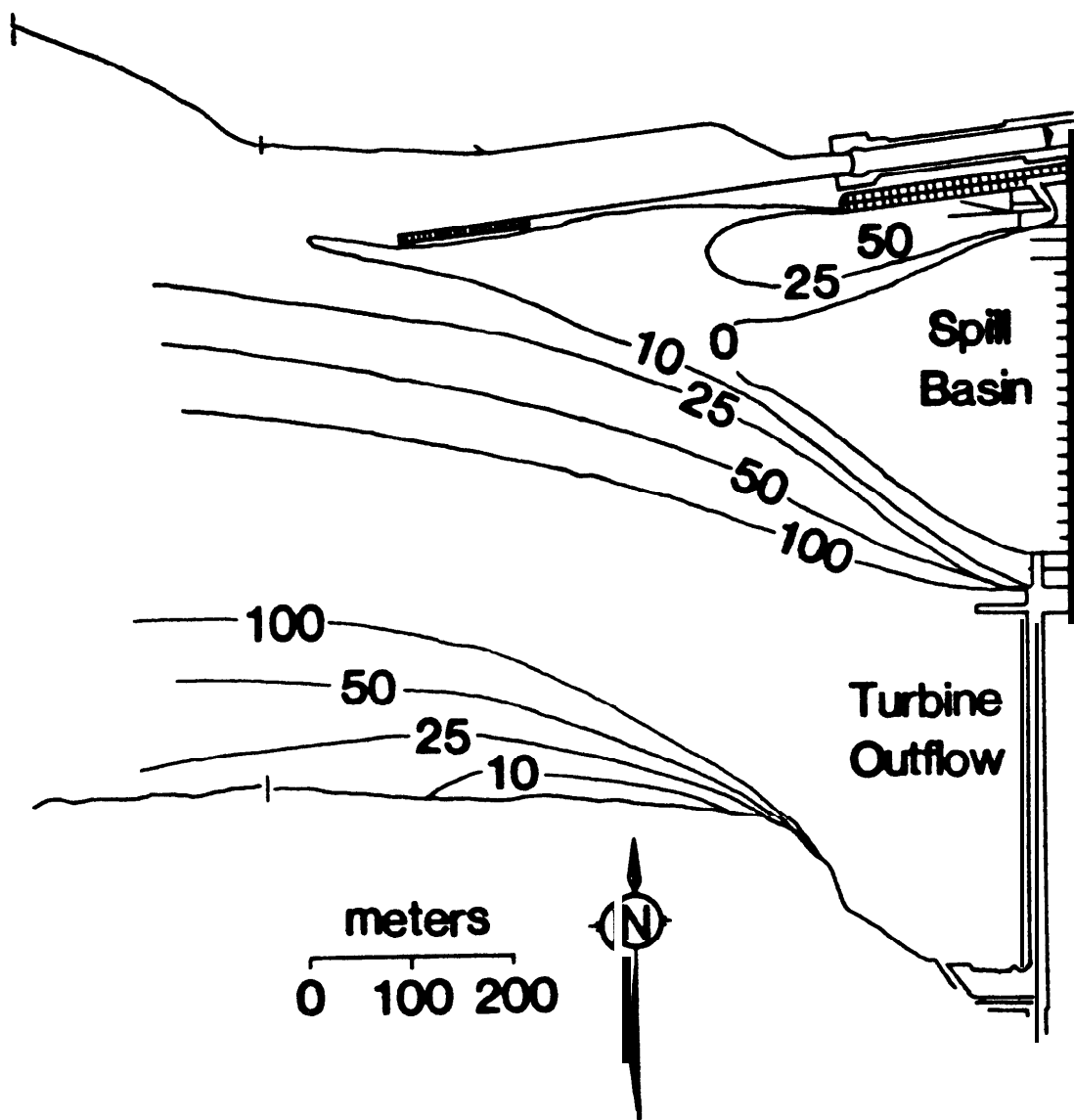
Figure 5. Typical isopleths of water velocities (cm/s) in McNary
tailrace, July and August **1985.**

predators, however 79.0% of the locations occurred in water velocities less than 50 cm/sec.

In spring and early summer, turbulence from spillgate operations and excessive discharge rates provided conditions that were not conducive to mapping velocities in the tailrace. We assume that velocities during high discharge rates and spillgate operations are invariably in excess of **100** cm/sec throughout the tailrace except for a small back-eddy mid-way along the navigation lock wall, a large slack-water area on the Oregon shore downstream of the turbine outflow and the slack-water area in the navigation lock channel. However, back-eddies or slack-water areas may exist in the spill basin if only a portion of the spillgates are opened, leaving points along the face of the dam without an origin of discharge. These conditions were common in **1985.** Northern squawfish observed in the spill basin during periods of high discharge were either in a back-eddy along the spillgates or were located there during a period of spill closure.

The movements of northern squawfish were also monitored during short term spill closures to determine how abrupt changes in discharge can affect their distribution. Four out of 5 northern squawfish monitored during short term spill closures in May, **1985,** moved out of protected areas and into the main river channel shortly after the spillgates closed. Two of these fish who were initially located along the navigation lock wall moved into close proximity of the by-pass outflow and the Washington shore adult fishway entrance (Fig. 6). Those fish that moved into the main river channel were observed the following day back in protected areas after the spillgates were reopened. Small sample sizes precluded the use of statistical analyses on spill closure movements.

SUMMARY AND CONCLUSION

Northern squawfish were associated with protected shoreline areas during periods of high water discharge, but moved into the main river channel and near the by-pass outflow when discharge decreased. Northern squawfish were commonly observed in areas of low water velocity. These results imply that predation by northern squawfish at fish passage facilities may be reduced by placing by-pass outflows in areas such that they are surrounded by high water velocity. The existing system at McNary Dam is efficient for reducing predator-prey interactions only during high discharge rates and spilling. Without spillgate operations, the north side of the by-pass outflow is exposed to a large slackwater area where northern squawfish were often located. However, by late summer when northern squawfish are congregated near the dam, all juvenile salmonids collected at the by-pass facility are transported by barge or truck; all outmigrants entering the tailrace do so through the turbines or adult fishways.
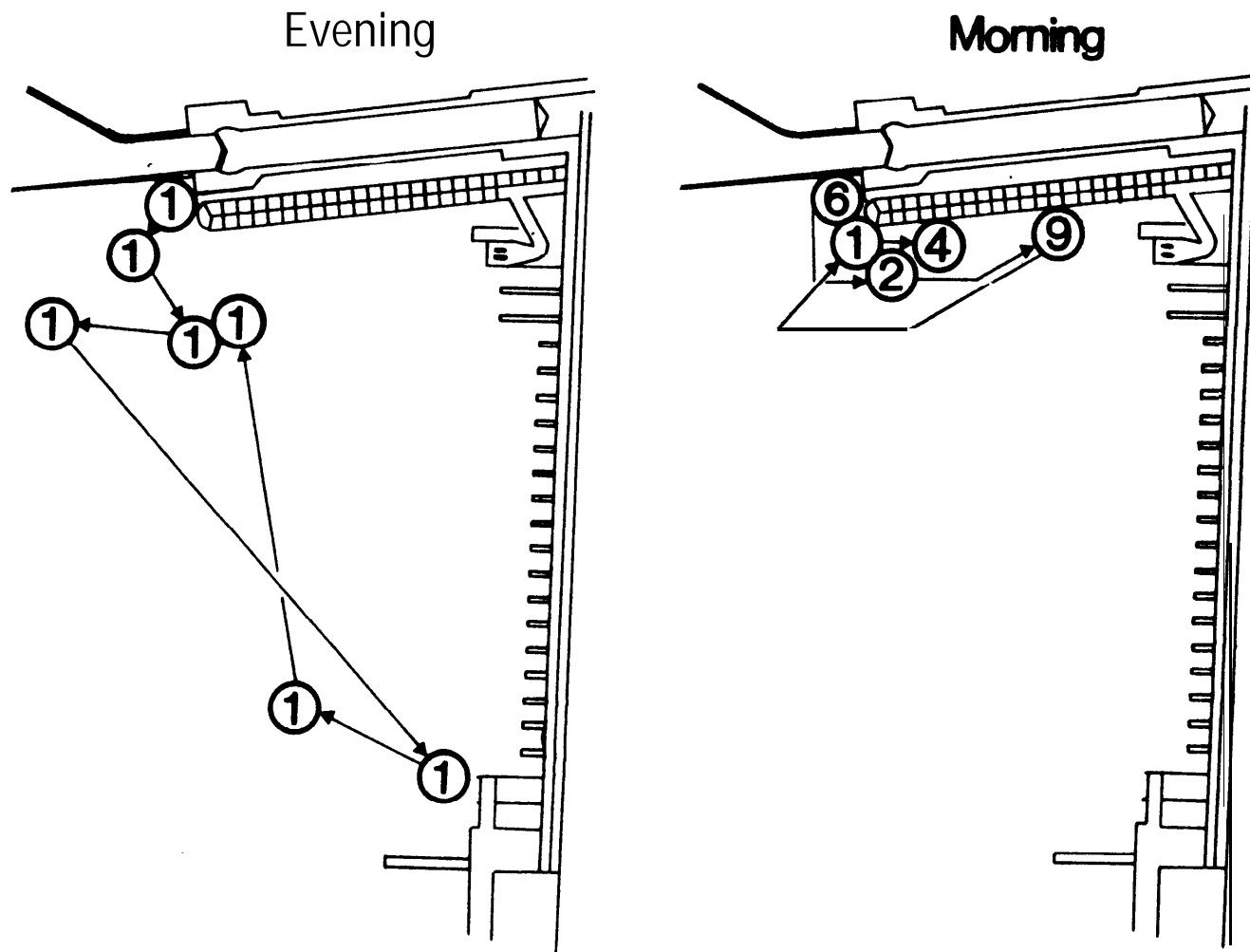
Figure 6. Movements of a radio-tagged northern squawfish near the Washington fishway after two spill closures (morning and evening) on May 7 and May 31, **1985,** McNary tailrace. Numbers within circles indicate the frequency of observations at each location.

The predators seem to stage at flow shears along the turbine outflow and adult fishway entrances, and are likely to be taking advantage of outmigrants passing through these facilities. However, the effects of the flow regime on predator distributions imply that only those outmigrants who drift toward the exterior boundaries of high velocity areas are subject to spatial interaction with northern squawfish. No evidence was found to document the movement of northern squawfish into high flow areas where they might prey on juvenile outmigrants. Smolt by-pass facilities with outlets that open into high velocity turbine outflows are currently in use at Bonneville and John Day dams on the Columbia River. Predator distributions in these areas should be examined to evaluate the effectiveness of this design in reducing the interaction of northern squawfish and juvenile salmonids during dam passage. Flow velocities at by-pass outlets need to be considered in the future design and location of by-pass facilities.

REFERENCES

Anonymous, 1980. Predation Management for the Peripheral Canal Fish
Facilities. Delta Fish Facilities Technical Coordinating Committee,
Working Justification Paper No. 5. Sept. 1980.

Bates, D.w. 1970. Diversion and Collection of Juvenile Fish with
Traveling Screens. U.S. Fish and Wildlife Service Fisheries Leaflet.
633 6 p. March 1970.

Gray, G.A., D.E. Palmer, B.L. Hilton, P.J. Connolly, H.C. Hansel, J.M.
Beyer, and G.M. Sonneville. 1983. Feeding activity, rate of
consumption, daily ration, and prey selection of major predators in
the John Day Pool. Annual Report to the Bonneville Power
Administration by U.S. Fish and Wildlife Service, Contract Number
DI-A179-82BP34796, Portland, OR, USA.

Hart L.G. and R.C Summerfelt. 1975. Surgical Procedures for
Implanting Ultrasonic Transmitters into Flathead Catfish (Pylodictis
olivaris). Transactions of the American Fisheries Society. 104
(1): 56-59.

Vogel. D.A. and J.G. Smith. 1984. Fish Passage Action program for
Red Bluff Diversion Dam. Annual Progress Report. Fisheries
Assistance Office, U.S. Fish and Wildlife Service, Red Cluff, CA,
USA.

Winter, J.D., V.B. Kuechle, D.B. Siniff, and J.R. Tester. 1978.
Equipment and methods for radio-tracking freshwater fish.
University of Minnesota Institute of Agriculture, Miscellaneous
Report 152, St. Paul, MN, USA.

Size Selectivity and Bias in Estimates of Population
Parameters of Smallmouth Bass, Walleye, and Northern
Squawfish in a Columbia River Reservoir

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Size selectivity of sampling gear is a widely recognized problem in fisheries (Hayes 1983; Hubert 1983; Lagler 1978; Reynolds 1983; Ricker 1975). All sampling gear are selective to some degree (Gulland 1980) because of intrinsic or extrinsic factors (Lagler 1978). Intrinsic factors such as fish behavior or habitat-preferences, determine which fish encounter the gear. Extrinsic factors, including construction of the gear and method of operation, determine if fish that encounter the gear are retained. If ignored, unequal vulnerability of fish of different sizes to capture can result in biased estimates of population parameters such as abundance, size structure, and mortality (Hamley 1975; Ricker 1975).

Bias could be eliminated if differences in vulnerability could be measured (Lagler 1978). Unfortunately, size selectivity is difficult to measure (Hamley 1975). Most measurements are based on indirect observations such as size frequencies and are expressed relative to the most vulnerable size group (Hamley and Regier 1973). However, where a variety of gear are used, relative vulnerabilities within a gear cannot be combined to estimate the net vulnerability to all gear without an estimate of among gear differences in vulnerability. The most vulnerable size groups are often assumed to be equally vulnerable to capture in each gear but this assumption is seldom met (Hamley and Regier 1973). Direct estimates of vulnerability to gear based on mark and recapture studies can be combined to calculate the net selectivity for each size of fish in a pooled sample but direct estimates of vulnerability have been made only for a few fish in selected habitats (Hamley and Regier 1973).

Instead of measuring and adjusting for differential vulnerability, sampling is often designed to minimize selectivity. Selectivity may be minimized by excluding fish near the limits of vulnerability, using less selective types of gear, dividing samples into subcategories, or using a variety of gear (Lagler 1978, Ricker 1975). These alternatives to measuring and adjusting for size selectivity may sacrifice precision and may not eliminate bias. Sample sizes are often limited and excluding samples from near the limits of vulnerability to a selected gear may sacrifice information. Seber (1982) describes the loss of precision in estimating abundance that results when a population is split into subcategories to eliminate vulnerability differences and sample sizes are reduced. Sample sizes and precision also are reduced when use of more effective gear is precluded by their selective nature. Using several gear types may broaden the range of sizes sampled but may not eliminate size bias because individual gear biases may not offset each other.

We recently completed a study of fish populations in a Columbia River reservoir where a multigear sampling approach was adopted in an attempt to compensate for size-related selectivity and represent population structures for routine population analyses. The objectives

Abstract. - We sampled smallmouth bass *(Micropterus dolomieui),* wall eye *(Stizostedion vitreum),* and northern squawfi sh *(Ptychocheilus oregonensis)* in John Day Reservoir on the Columbia River from 1983-86 with five types of gear: two types of gillnets, boat electrofishers, trapnets and angling. Different gears selectively sampled different sizes of each species. Recapture rates indicated that different sizes of fish remained differentially vulnerable to capture in pooled gear samples. Vulnerability of smallmouth bass and walleye declined with increasing size. Vulnerability of northern squawfish increased with size. Size selectivity of gear resulted in estimates of abundance potentially biased by 2 to 16% estimates of proportional stock density (size structure) biased by 11 to 46% and estimates of annual rate of mortality biased by 17 to 69%. The bias was negative in estimates of abundance and varied in estimates of size structure and mortality dependant on the pattern of vulnerability. In any long term monitoring of a population, investigation of the nature of the bias resulting from size selectivity would seem prudent.
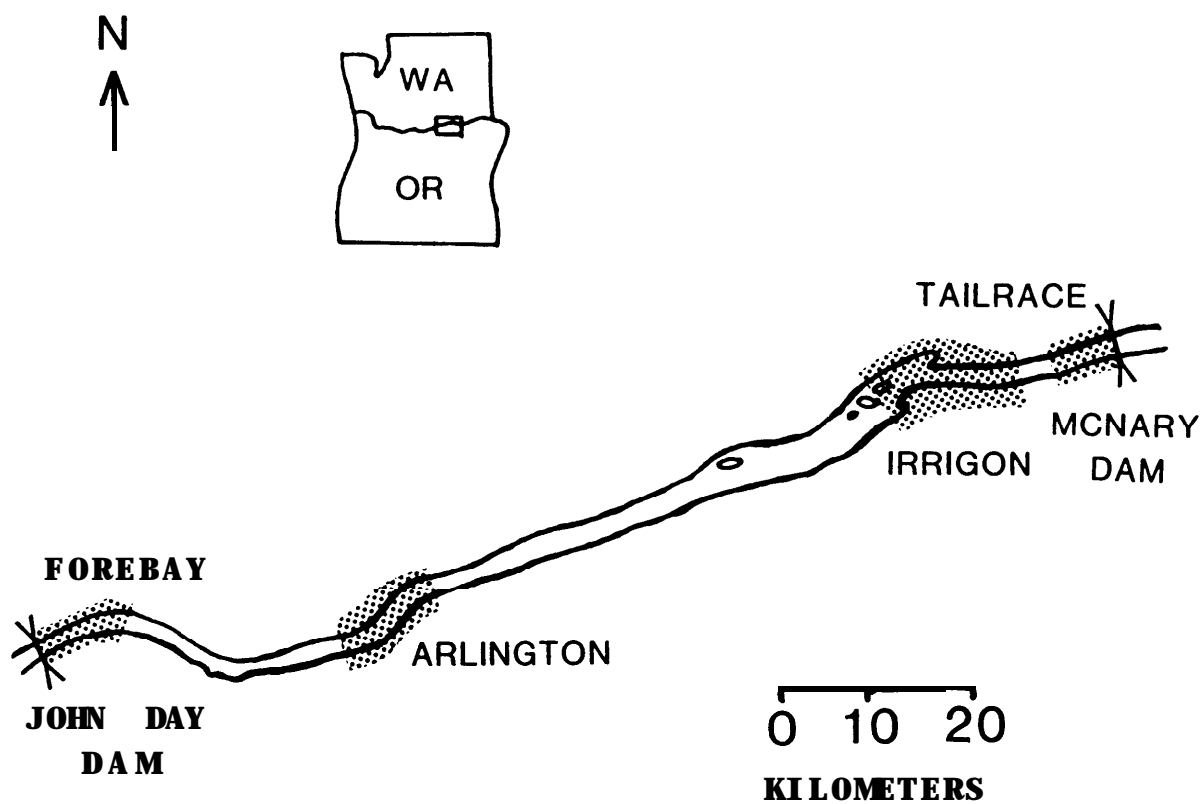
Figure 1. John Day Reservoir, Columbia River. Sampled areas are shaded.

of this paper are to 1) describe size selectivity of five gears used to sampl e smallmouth bass *(Micropterus dolomieui),* wall eye *(Stizostedion vitreum),* and northern squawfish *(Ptychocheilus oregonensis))* in a Columbia River reservoir, 2) describe size selectivity present in combined gear samples, and 3) determine potential biases in estimates of abundance, size structure, and mortality if size selectivity were ignored.

Study Si te

John Day Reservoir is one of a series of impoundments operated for hydroelectric power generation, navigation and flood control on the lower Columbia River between Oregon and Washington (Figure 1). The reservoir is 123-km long, up to 3,5km wide, and has a surface area of about 20,000 hectares. The reservoir is bounded by John Day (Rkm 348) and McNary (Rkm 471) Dams. A variety of habitats occur in John Day Reservoir. The upper reservoir is more riverine although high inflows result in measureable current throughout the reservoir." Offshore depths range from 10 m in the upper end of the reservoir to 50 m in the lower section. Shorelines are typically steep and littoral zone is limited.

Methods

We sampled four portions of John Day Reservoir from $A_p$ril through June, 1983 to 1986 (Figure 1). Each area was sampled with equal effort during each of five consecutive, two-week periods. Fish were collected with two types of monofilament gill nets (45.6-m long by 2.4-m deep with alternating panels of 3.2, 4.4, and 5.1-cm mesh and 45.6-m long by 2.4-m deep with alternating panels of 6.4 and 7,6-cm mesh), Lake Erie style trap nets (3 or 5-m deep with 61-m long leads of 3.2 or 3.8-cm bar mesh), electrofishing boats, and by angling from John Day and McNary Dams. Units of sampling effort were one hour for gillnets, 24 hours for trapnets, and 15 minutes current-on time for electrofishers. Gillnets were set on the bottom, near and perpendicular to shore. Trapnets were set perpendicular to shore with the lead end abutting the beach. Electrofishing runs were made along shorelines and dam faces. All sampling was done at night. In addition, we examined the catch of sport anglers fishing in forebay, Irrigon and tailrace areas.

Smallmouth bass, northern squawfish and walleye were captured, counted and measured. Fish in good condition were released after marking with numbered spagetti tags and pelvic fin clips or opercle punches. Tagging was limited to smallmouth bass at least 200 mm in fork length and northern squawfish and walleye at least 250 mm in fork length. Subsequent recaptures of marked fish were counted. Scales were collected from a subsample of fish and aged using standard methods (Jearld 1983).

We compared length frequencies of each species among gear to determine whether any gear selectively sampled fish with respect to size (Lagler 1978). Significant (p<0.05) differences in length frequencies
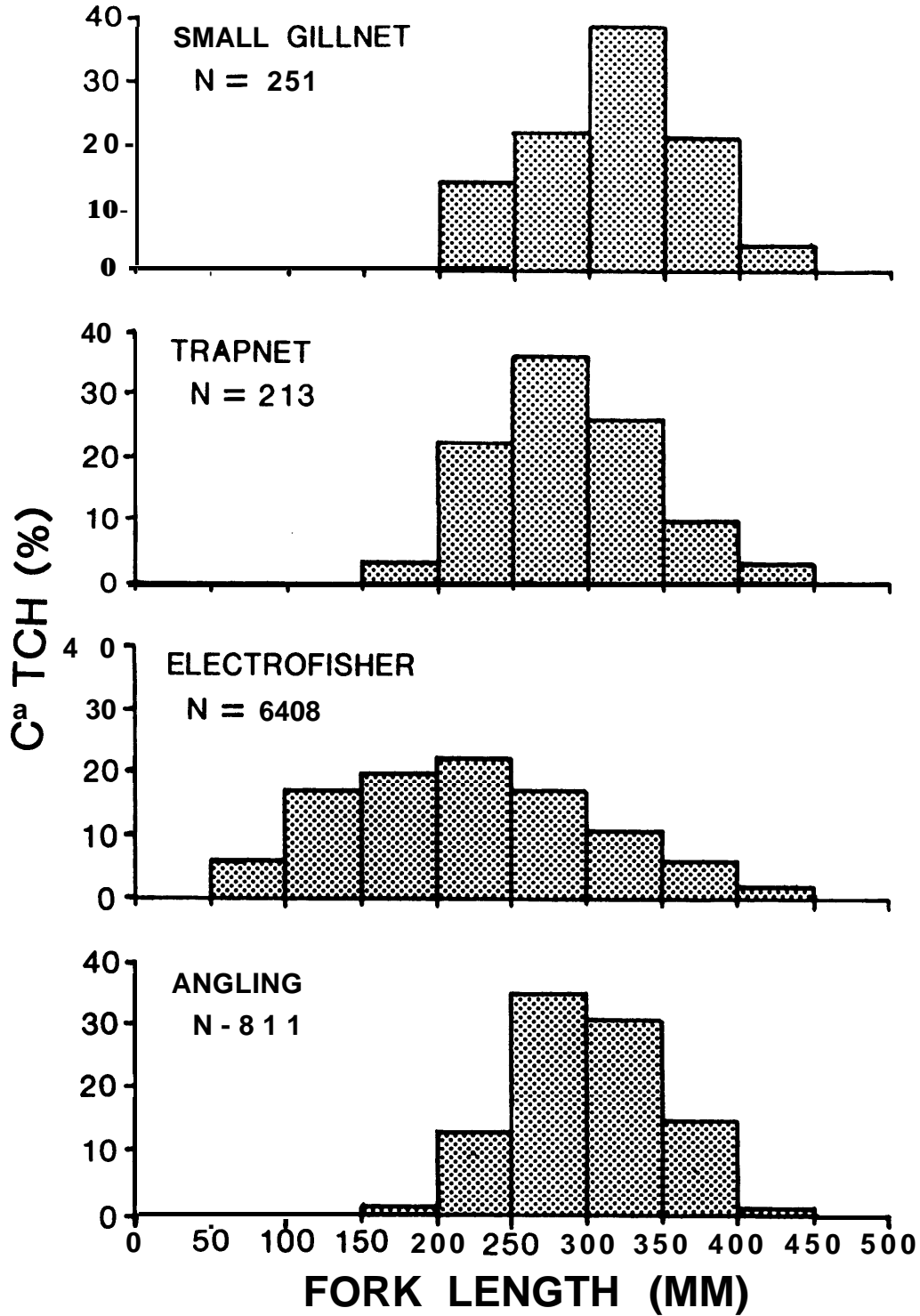
Figure 2. Length-frequency distributions of smallmouth bass collected in John Day Reservoir by four gears.

among gear were identified with chi-square tests for independence between gear and lengtth(Steel and Torrie 1980). Samples which contributed less than 100 fish were excluded from comparisons because tests were invalid at low sample sizes.

To determine if a sample including all gear selected for different sizes of fish, we compared numbers of recaptures to marked fish available among 50-mm size groups (Lagler 1978). Significant differences among different sized fish were identified with chi-square contingency tests (Youngs and Robson 1978). Samples from all two-week sampling periods were pooled for a two-way analysis. Lines describing relationships between vulnerability and size were fit with least squares regressions (Steel and Torrie 1980).

We estimated the potential influence of size selectivity on estimates of abundance, population size structure, and mortality rate by comparing estimates made with and without corrections for size selectivity. Abundance was estimated from mark and recapture information with Chapman's modification of the Schnabel method (Seber 1982). To correct for size selectivity, we made separate estimates of abundance for size classes where vulnerability appeared similar (Ricker 1975). We report an average of annual estimates of abundance made from 1984-86.

Population size structure was estimated from a length frequency distribution (1983-86 samples pooled). Size structure was described as a proportional stock density (PSD) (Anderson 1980). Stock and quality sizes were arbitrarily defined as 18 cm and 28 cm for smallmouth bass, 25 cm and 38 cm for walleye, and 25 cm and 38 cm for northern squawfish. Data were corrected for size selectivity by dividing the observed frequency in each size class by its relative vulnerability (Lagler 1978).

Mortality was estimated by catch curve (Ricker 1975) using age frequencies calculated from length frequencies and age at length information (Ketchen 1950). Selectivity effects on mortality were corrected using length frequencies adjusted for size selectivity by dividing each frequency by the relative vulnerability to capture for that size.

Results

Smallmouth Bass

We collected different sizes of smallmouth bass with different gear (Figure 2). Differences in length frequencies were significant for fish larger than 200 mm ($X^2=285.9$; df-15; $P<0.01$).

We also found differential size vulnerability of smallmouth bass in our pooled gear sample (Figure 3). Differences in ratios of recaptures to marked-fish-at-large ratios were significant among 50-mm size groups ($X^2=26.0$; df=5; $P<0.01$). Vulnerability declined linearly ($r^2=0.86$) with

Figure 3. Ratio of recaptures to marks at-large (vulnerability) for smallmouth bass by length interval, John Day Reservoir, April-June 1983-86. Numbers of marks at-large summed for 24 two-week periods are included for each point. A straight line describing the relationship was fit to ratios with the least squares method.

increasing size (Figure 3). The least vulnerable size class (451-500 mm) was one third as vulnerable as the most vulnerable size class (201-250 mm).

All population parameters of smallmouth bass were potentially biased by size selectivity of the combined gear (Table 1). Abundance estimates corrected for vulnerability differed by less than 2%. Potential bias was larger in estimates of PSD and annual mortality. Under-representation of large smallmouth bass in our catch resulted in biases of -20% in the estimate of PSD and +22% in the estimate of annual mortality rate.

Walleye

Size of walleye sampled also varied by gear (Figure 4). Differences in length frequencies were significant for fish larger than 200 mm ($X2=726.2$; df=33; P<0.01).

Our data suggest that differential vulnerability to capture was not eliminated in the pooled gear sample (Figure 5). Differences in recapture-to-at-large ratios were significant among 50-mm size groups ($X^2=103.8$; df=10; p<0.01). Vulnerability appeared to decrease dramatically with increasing walleye size above 450 mm (Figure 5). We estimate that fish larger than 500 mm may have been one third as vulnerable as fish in the 351 to 450-mm size group. Estimates of vulnerability of walleye less than 351 mm were excluded because of small sample sizes. A normal curve appeared to describe the size-vulnerability relationship among walleye (Figure 5).

Estimates of walleye abundance, PSD, and mortality were influenced by the apparent size selectivity of our gear (Table 2). Abundance was underestimated by 16%. PSD was underestimated by 11%. Estimated annual mortality was overestimated by 17%.

Northern Squawfish

Different gears took different sizes of northern squawfish (Figure 6). Differences in length frequencies were significant for fish larger than 250 mm ($X2=2634.7$; fd=15; P<0.01). Differences in size-related vulnerability also were not eliminated in our pooled gear sample (Figure 7).

Differences in recapture to at-large ratios were significant among 50-mm size groups ($X*=15.1$; df=4' P<0.01). Vulnerability appeared to increase with size among northern squawfish up to 450 mm (Figure 7). Fish in the 401 to 450-mm size range were approximately three times more vulnerable than fish smaller than 350 mm A normal curve appeared to describe the size-vulnerability relationship among northern squawfish (Figure 7).

Table 1. Parameters of the smallmouth bass population in John Day Reservoir based on estimates with and without corrections for size selective sampling.

Population Parameter	Corrections Included?	
	No	Yes
Abundance	9, 805	9, 946
Size Structure (PSD)	48	60
Annual Mortality (Ages 3-9)	0. 45	0. 37

Table 2. Parameters of the walleye population in John Day Reservoir based on estimates with and without corrections for size selective sampling.

Population Parameter	Corrections Included?	
	No	Yes
Abundance	16, 212	19, 387
Size Structure (PSD)	88	99
Annual Mortality (Ages 6-9)	0.56	0.48

Table 3. Parameters of the northern squawfish population in John Day Reservoir based on estimates with and without corrections for size selective sampling.

Population Parameter	Corrections Included?	
	No	Yes
Abundance	87,513	97,084
Size Structure (PSD)	51	35
Annual Mortality (Ages 5-13)	0.04	0.13
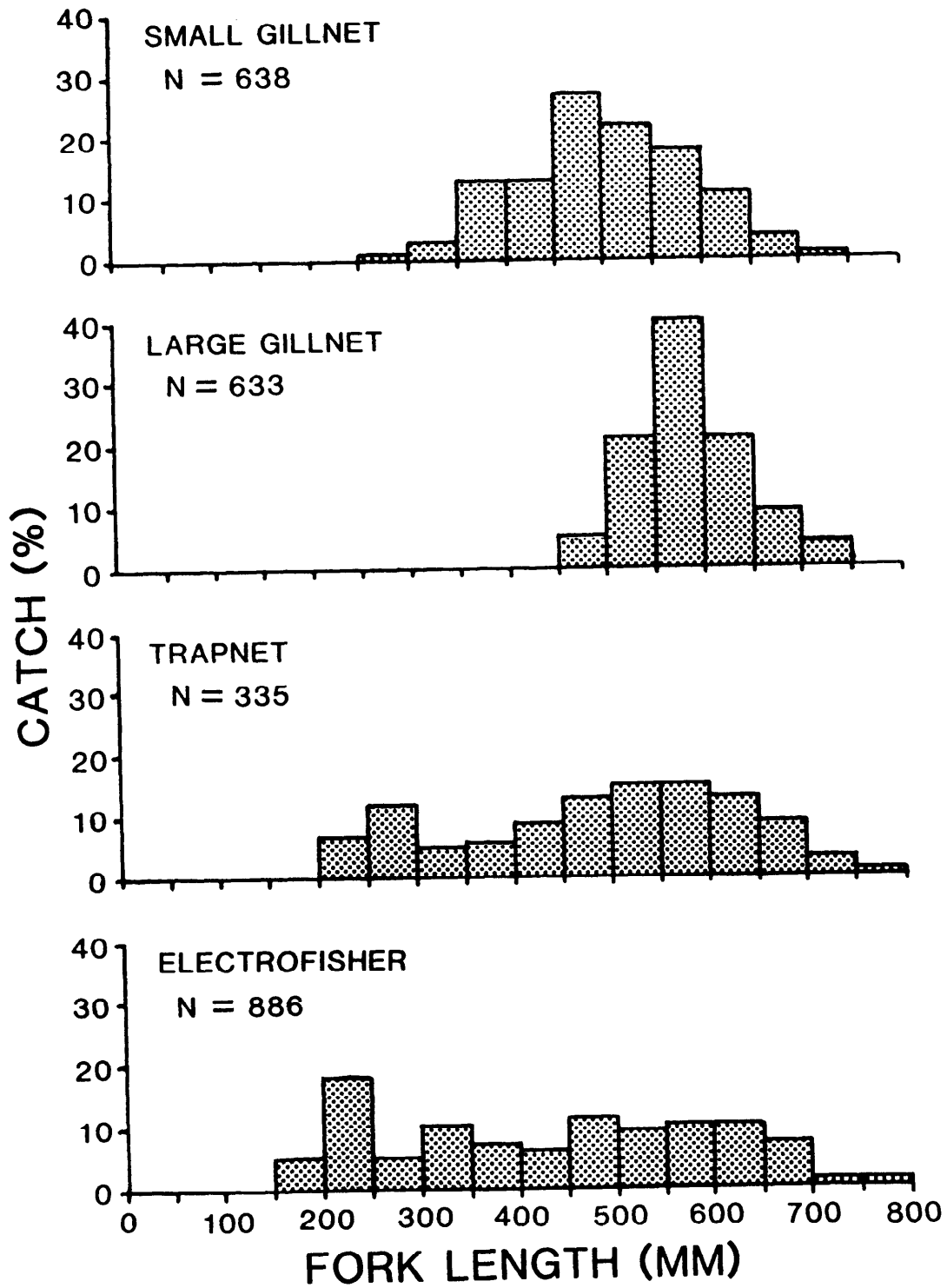
Figure 4. Length-frequency distributions of walleye collected in John Day Reservoir by four gears.

$$Y = 0.0536 \, e^{\dfrac{-(376.1-X)^2}{9577.3}}$$

$$R^2 = 0.98$$
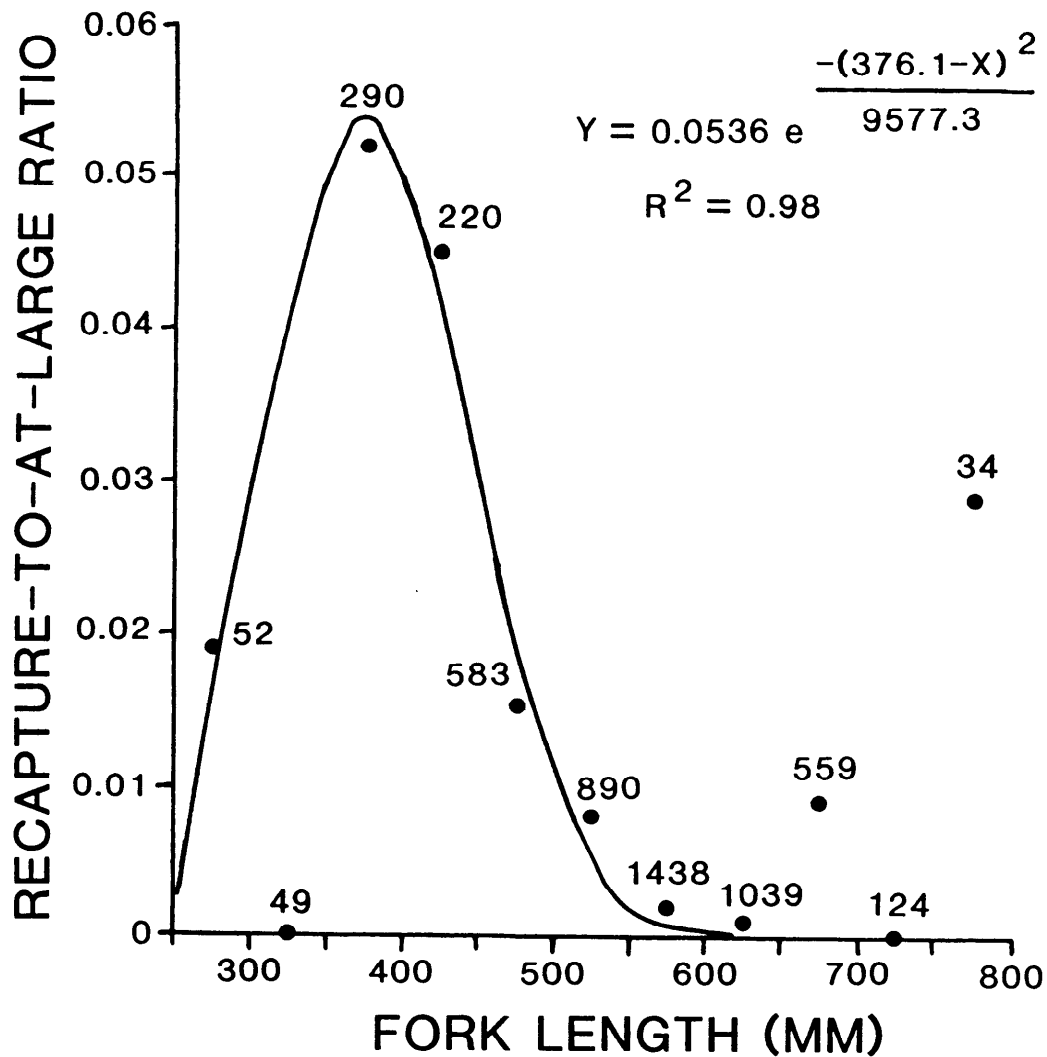
Figure 5. Ratio of recaptures to marks at-large (vulnerability) for walleye by length interval, John Day Reservoir, April-June 1983-86. Numbers of marks at-large summed for all 24 two-week periods are included for each point. A normal curve describing the relationship was fit to ratios with the least squares method omitting points at 325 and 800 mm.
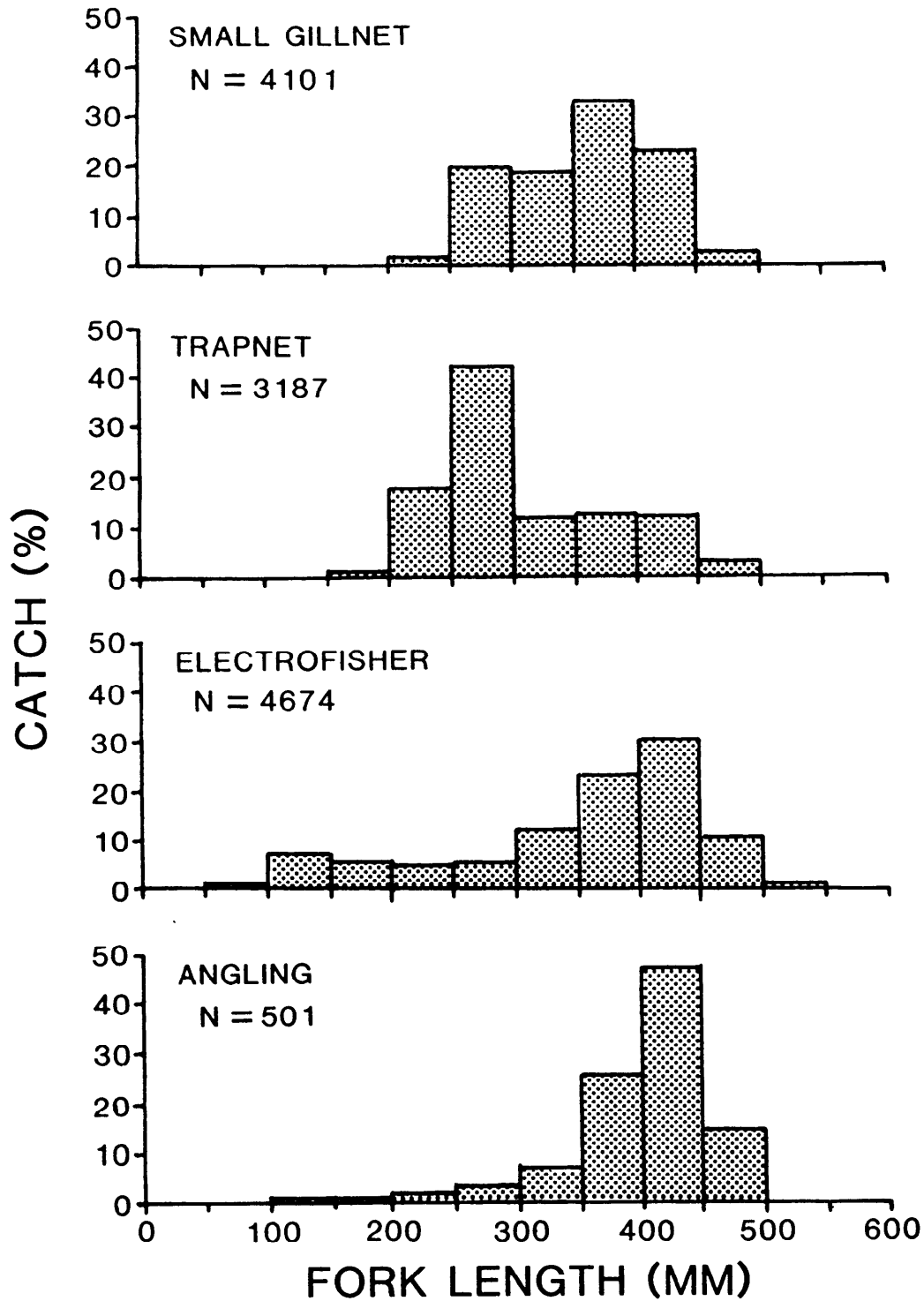
Figure 6. Length-frequency distributions of northern squawfish collected in John Day Reservoir by four gears.
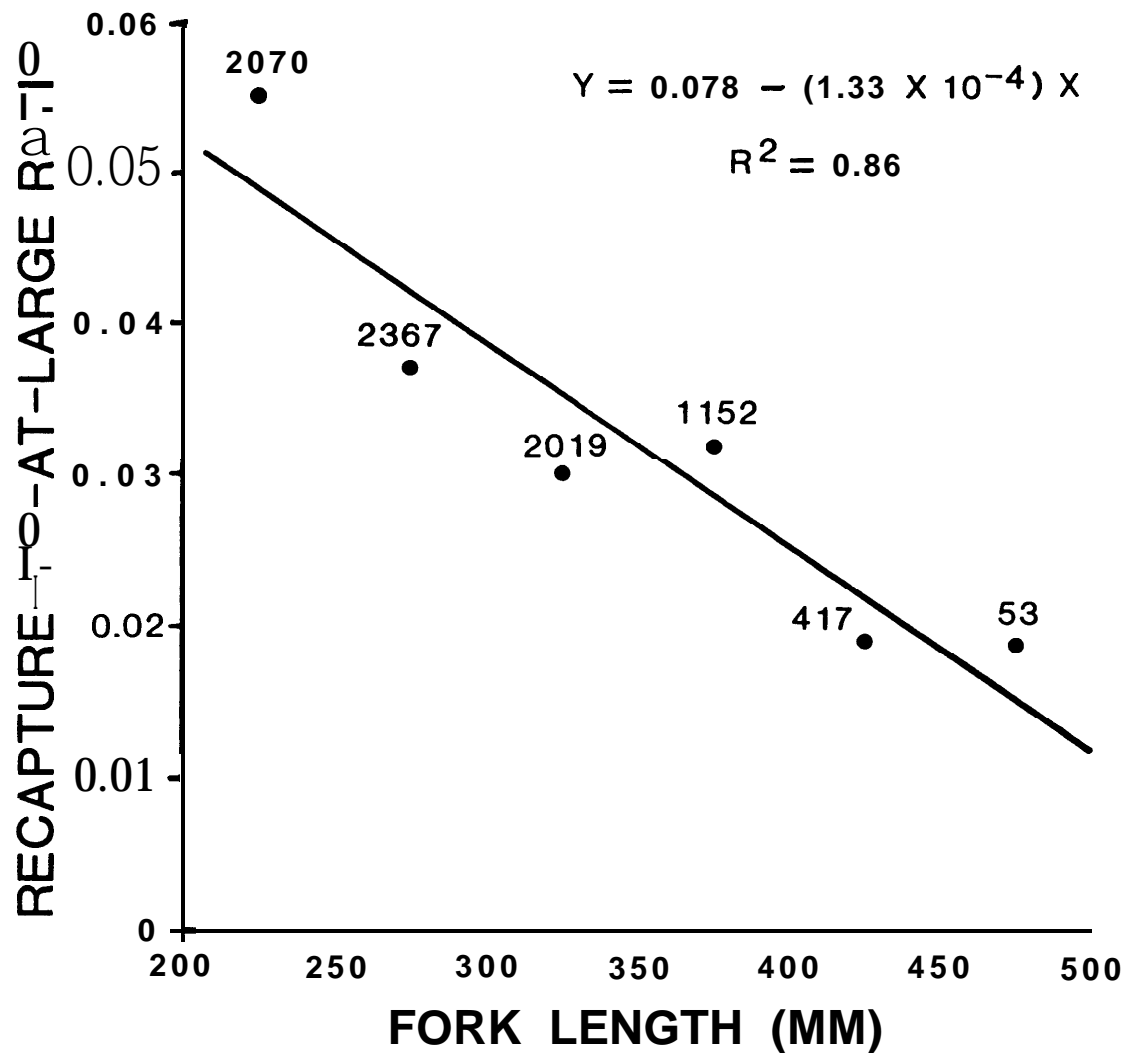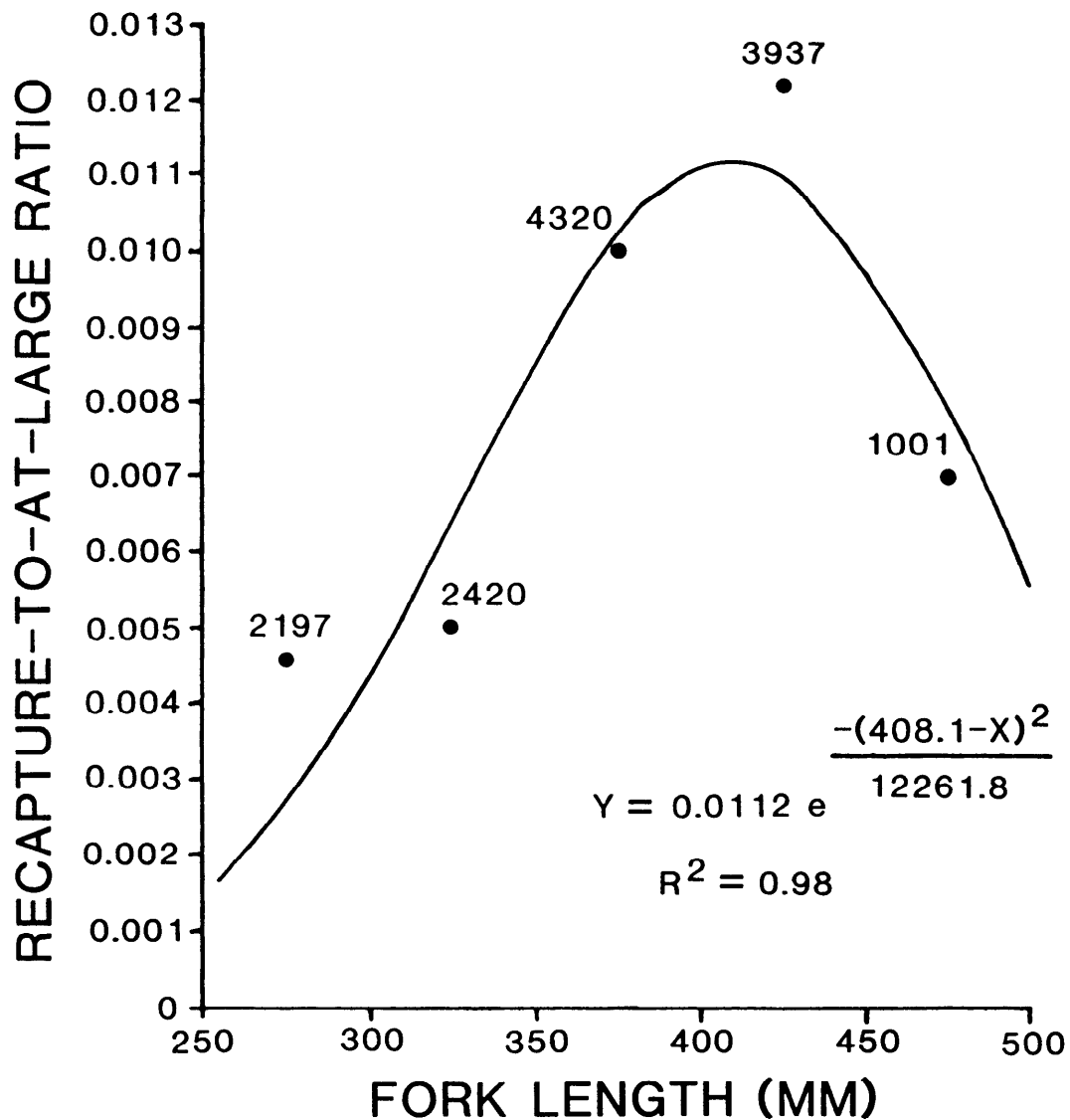
Figure 7. Ratio of recaptures to marks at-large (vulnerability) for northern squawfish by length interval, John Day Reservoir, April-June 1983-86. Numbers of marks at-large summed for 24 two-week periods are included for each point. A normal curve describing the relationship was fit to ratios with the least squares method.

Apparent size selectivity of gear resulted in potentially biased estimates of northern squawfish abundance, size structure, and annual rate of mortality (Table 3). Corrected and uncorrected abundance differed by 10%, PSD estimates differed by 46%, and annual mortality estimates differed by 69%.

Discussion

Differences in recapture to at-large ratios indicate pooling samples from size selective gear did not eliminate selectivity in the combined sample for any of the populations examined. Selectivity would be eliminated only if selectivities of each gear balanced exactly, ie. each gear selected for a different size range of fish at an equal rate. This is probably an unreasonable expectation in almost any sampling since the relative selectivities cannot be predicted in advance.

Low recapture numbers and high variability of recapture-to-at-large ratios limited our ability to describe changes in vulnerability with size, especially for walleye and northern squawfish. This problem was most acute near the extremes in sizes vulnerable to our collective sampling because small sample sizes biased recapture-to-at-large ratios towards zero.

The pattern of size selectivity was species specific. Vulnerability to capture declined gradually with increasing size among smallmouth bass, declined abruptly with increasing size among walleye and increased abruptly over a small size range among northern squawfish.

Decreasing vulnerability of smallmouth bass and walleye to capture with increasing size may have been a result of larger fish using a broader range of habitats or areas than smaller fish. Reduced vulnerability among larger fish would be explained if larger fish spent less time near shore where most samples were taken or if large fish were more likely to move outside sampled sections of the reservoir. Offshore movements have been found to reduce catchability of largemouth bass *(Micropterus salmoides)* (Van Den Avyle 1976). Sex differences in size of maturity and behavior during spawning may also have contributed to differences in vulnerability of walleye. Male walleye mature at smaller sizes than females, arrive at spawning sites earlier, and stay longer (Colby et al. 1979). Males could have been over-represented in the catch if sampling were concentrated near spawning sites.

We have no explanation for the increased vulnerability of northern squawfish with size. The shift may be related to feeding activity and distribution. Northern squawfish become almost entirely piscivorous in the size range where vulnerability changes (Gray and eleven coauthors 1986). A corresponding change in foraging behavior with increased size may have resulted in fish spending more time in areas we sampled. Larger northern squawfish were increasingly piscivorous and may have spent more time near shore where small fish appeared most abundant and our sampling was concentrated.

Estimates of abundance, population size structure, and annual mortality rates for all three species were susceptable to size selective bias. Bias in estimates of abundance ranged from 2% to 16% and were similar to those reported in Ricker (1975) for comparable experiments. Estimates of PSD were biased by 11 to 46%. Estimates of annual mortality were biased by as much as 69%. The relatively small bias in abundance estimates may not warrant correcting for size selectivity. Precision is sacrificed by making separate estimates for differentially vulnerable size classes (Seber 1982) and the loss of precision must be weighed against the desire for increased accuracy.

The pattern of selectivity determined the direction of the bias except in estimates of abundance. Bias was always negative in estimates of abundance when sampling was size selective. In estimates of PSD, bias was negative where vulnerability declined with increasing size and positive where vulnerability and size were inversely correlated. Annual mortality was overestimated when gear selected against larger fish and underestimated when gear selected against smaller fish.

Our data show that substantial bias can result in estimates of population characteristics when sampling is based on size selective gear. Pooling gear types in an effort to represent several species and habitat types did not eliminate the potential for error, particularly for estimates of PSD and mortality based on relative size structure of our samples. Our data also show that the direction and magnitude of the bias may vary dramatically by species.

Fishery managers routinely collect population age or size structure data. Often sample size is limited or data are collected in an inconsistent fashion, making estimates of size-related vulnerability impractical. Fisheries managers should exercise caution in the use of such data. In any long term monitoring of a population, investigation of the nature of the bias would seem prudent.

Acknowledgments

References

Anderson, R. O. 1980. Proportional Stock Density (PSD) and Relative Weight (Wr): interpretive indices for fish populations and communities. Pages 27-33 *in* S. Gloss and B. Shupp, editors. Proceedings of the First Annual Workshop, Practical Fisheries Management: More with less in the 1980's. New York Chapter, American Fisheries Society.

Colby, P.J., R.E. McNicol, and R.A. Ryder. 1979. Synopsis of biological data for walleye, *Stizostedion vitreum* (Mitchell 1818). Food and Agriculture Organization of the United Nations Fisheries Synopsis Number 119.

Gray, G.A., and eleven coauthors. 1986. Feeding activity, rate of consumption, daily ration, and prey selection of major predators in John Day Reservoir, 1984. U.S. Fish and Wildlife Service Annual Report to Bonneville Power Administration, Contract DE-AI79-82BP34-796, Portland, Oregon.

Gulland, J.A. 1980. General concepts of sampling fish. Pages 7-12 *in* T. Backiel and R.L. Welcomme, editors. Guidelines for sampling fish in inland waters. European Inland Fisheries Advisory Commission Technical Paper 33. Food and Agriculture Organization of the United Nations, Rome Italy.

Hamley, J.M. 1975. Review of gillnet selectivity. Journal of the Fisheries Research Board of Canada 32:1943-1969.

Hamley, J.M, and H.A. Regier. 1973. Direct estimates of gillnet selectivity to walleye. Journal of the Fisheries Research Board of Canada 30:817-830.

Hayes, M.L. 1983. Active fish capture methods. Pages 123-146 in L.A. Nielson and D.L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Hubert, W.A. 1983. Passive Capture Techniques. Pages 95-122 in L.A. Nielson and D.L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Jearld, A.,Jr. 1983. Age determination. Pages 301-325 *in* L.A. Nielson and D.L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Ketchen, K.S. 1950. Statified subsampling for determining age distributions. Transactions of the American Fisheries Society 79:205-212.

Lagler, K.F. 1978. Capture, sampling and examination of fishes. Pages 7-47 in T. Bagenal, editor. Methods for assessment of fish production in fresh waters, 3rd edition. Blackwell Scientific Publications, London.

Reynolds, J.B. 1983. Electrofishing. Pages 147-164 *in* L.A. Nielson and D.L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Seber, G.A.F. 1982. The estimation of animal abundance and related parameters, 2nd Edition. MacMillan Publishing Company, Inc., New York.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. McGraw-Hill, New York.

Van Den Avyle, M.J. 1976. Analysis of seasonal distribution patterns of young largemouth bass *(Micropterus salmoides)* by use of frequency-of-capture data. Journal of the Fisheries Research Board of Canada 33:2427-2432.

Youngs, W.D., and D.S. Robson. 1978. Estimation of population number and mortality rates, 3rd edition. Pages 137-164 in T. Bagenal, editor. International Biological Programme Handbook Number 3. Blackwell Scientific Publications, Oxford.

MOCPOP: A Flexible Simulator for Analysis of
Age-Structured Populations and Stock-Related Functions

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WHAT IS MOCPOP?

MOCPOP is a program for simulating annual variation in a population of organisms based on recruitment, mortality, and growth. Commonly used models of population dynamics (Vaughan et al. 1982), including stock-recruitment, logistic (surplus production), dynamic pool (yield), and Leslie matrix or combinations or portions of these models can be approximated with MOCPOP. MOCPOP tracks population size in numbers and biomass, and also calculates numbers of particular interest to harvest managers including yield, number of harvestable individuals, and an index of population size structure.

I wrote this software to simplify use of the computer in modeling populations. It provides the flexibility to simulate a variety of populations and population processes with a minimum of experience with. microcomputers and no knowledge of computer language or programming. MOCPOP was adapted from population models outlined by Taylor (1981) and Walters (1969) but with greater flexibility in reproduction and recruitment processes. Programming was built around processing to aide manipulation of input population parameters and inspection of simulation results.

HOW TO RUN MOCPOP

To run MOCPOP you must:

1.   Boot machine with PC-DOS or MS-DOS.

2.   Place diskette containing model in default drive.

3.   Start the model (type MOCPOP10 after > prompt and press Enter).

The program may be interrupted by pressing Control+Break or exited by selecting the Quit Option (#13) in the Output Options Menu (See page 3).

MOCPOP is written in compiled Microsoft QuickBASIC v4.0 to run on IBM and IBM-compatible machines. Graphics require an IBM color graphics adaptor or a functional equivalent. Hercules monochrome graphics cards are not supported.

HOW MOCPOP WORKS

MOCPOP is organized into 3 parts. The input section prompts the user to select processes that describe their population and to supply appropriate starting numbers and parameters. The processing section runs the appropriate simulation. The output section displays the results of the simulation.

Each time MOCPOP is executed, it writes inputs to a data file on the MOCPOP diskette. You are prompted for a name for this data file to which MOCPOP adds the extension .MPK. File names may be up to 8 characters long, typed in upper or lower case, and may include spaces. You may create any number of these data files with MOCPOP, but you must use the DOS command ERASE <filename> to remove them from your diskette. Instead of re-entering inputs each time you use MOCPOP, you may edit your earlier inputs and run a new simulation or you may rerun a simulation with inputs entered previously. MOCPOP will check the diskette for files with the extension .MPK, list these files, and prompt you to select one.

Execution of the program is controlled from two main menus and one submenu. The "Run Option Menu" is displayed when the program is started and controls the input process. Run Options include:

1. BUILD A NEW MODEL.

2. EDIT SELECTED INPUTS IN AN EXISTING MODEL.

3. RUN EXISTING MODEL WITH DEFAULT OR EDITED INPUTS.

Run Option #1 builds a new model from scratch. Run Option #1 prompts for a name to assign the file in which inputs for the new model are to be saved, then steps through each input one at a time before starting the simulation. The Build a New Model Option (Run Option #1) has no provision for going backward; you must press Ctrl+Break and restart if you make an entry error. Run Option #2 uses inputs from a previous simulation but allows changes before the simulation starts. Run Option #2 displays names of files containing inputs from previous simulations, prompts you to select a file, gives you the option of renaming the file, then displays a list of inputs that may be changed in an "Edit Options Submenu". You select the desired inputs, make changes, and start the simulation from the "Edit Options Submenu" (See page 4). The Edit Selected Inputs Option (Run Option #2) lets you go back and change inputs you've already passed by reselecting the same option from the menu. Run Option #3 immediately starts the simulation after prompting you for the name of the file containing desired inputs.

The "Output Options Menu" is displayed when the simulation is completed. Output Options include:

1. LIST INPUT INFORMATION.

2. LIST REPRODUCTION BY AGE.

3. LIST POPULATION BY AGE.

4. LIST HARVEST, YIELD, AND EFFECT BY AGE.

5. LIST POPULATION BY YEAR.

6.   CALCULATE SUMMARY STATISTICS FOR POPULATION OVER TIME.

7.   PLOT SELECTED VARIABLES.

8.   WRITE BY-AGE RESULTS TO FILE.

9.   WRITE BY-YEAR RESULTS TO FILE.

10.   CONTINUE PRESENT SIMULATION WITH NEW PARAMETERS.

11.   RETURN TO START FOR NEW SIMULATION.

12.   TEMPORARY RETURN TO DOS (SHELL).

13.   QUIT.

Output Option #1 displays a summary of inputs upon which the current results are based. Output Options #2-4 list age-specific numbers in the last year of the simulation. Output Option #5 lists a summary of population numbers in each year of the simulation. output Option #6 calculates mean, range, and standard deviation of population numbers over a selected time interval. Output Option #7 plots simulation results as a line graph. Output Options #8-9 write simulation results to a diskette file. Output Option #10 allows the current simulation to be continued after returning to the input section and changing parameters. Output Option #11 returns to the Run Option Menu to start a new simulation. Output Option #12 allows a temporary return to DOS without losing simulation results. Output Option #13 ends execution of MOCPOP and returns to DOS. A more detailed discussion of Output Options #1-10 can be found in the section on output.

<center>INPUT</center>

In the input section, MOCPOP sequentially prompts you to select processes that describe your population and to enter appropriate starting numbers and parameters. Default values for each input are read from the data file you selected and are displayed in brackets. Default values are also displayed for menu options to speed execution of the program. Defaults can be accepted by pressing Enter or changed by typing in a new value and pressing Enter. Inappropriate numbers will not be accepted and you will have to enter a new number. Commas in numbers are not accepted. Decimal fractions may or may not be preceeded with a zero. As appropriate inputs are entered, MOCPOP automatically advances to the next input or moves to the next screen.

Inputs are organized into seven categories, and each category corresponds to one screen in the input section. These screens are accessed in order by Option #1 in the Run Option Menu (build a new model) and are accessed selectively by Run Option #2 (edit selected inputs). Selection of Run Option #2 displays a listing of these

categories in the Edit Options Submenu. Input screens-categories in order are:

1.   YEARS TO RUN.

2.   MAXIMUM AGE AND STARTING POPULATION SIZE.

3.   RECRUITMENT.

4.   MORTALITY.

5.   LIFE HISTORY PARAMETERS.

6.   AGE SPECIFIC WEIGHTING FACTORS.

7.   AGE STRUCTURE INDEX.

Input Screen #1 prompts for the number of years to run the simulation. The starting year is year 1. A maximum of 300 years may be run.

Input Screen #2 prompts for maximum age and a starting population. The number of individuals must be entered for each age class. A maximum of 100 age classes may be entered. If the population has no age structure, enter a maximum age of 1.

Input Screen #3 prompts for the mechanism of recruitment and associated parameters. Recruitment is defined as the number of age 1 individuals at the start of the year. Recruitment can be varied independently or as a function of parental stock size.

Nine Recruitment Options exist:

1.   CONSTANT AT NUMBER ENTERED AS AGE 1 NUMBER ABOVE.

2.   CONSTANT AT AGE 1 INPUT EXCEPT FOR BIG YEAR CLASSES AT FIXED INTERVALS.

3.   CONSTANT AT AGE 1 INPUT EXCEPT FOR BIG YEAR CLASSES AT RANDOM INTERVALS.

4.   RANDOM WITH EQUAL CHANCE OVER A SPECIFIED RANGE.

5.   RANDOM NORMAL WITH SPECIFIED MEAN AND STANDARD DEVIATION.

6.   STOCK RELATED--PROPORTIONAL TO REPRODUCTIVE POTENTIAL.

7.   STOCKRELATED--BEVERTON-HOLTRELATIONSHIP.

8.   STOCK RELATED--RICKER RELATIONSHIP.

9.   STOCK RELATD-CUSHING RELATIONSHIP.

Recruitment Options #1-3 use the number of age 1 individuals entered in the starting population screen as an average condition. Recruitment Options #2-3 allow replacing this average recruitment with a severalfold increase at fixed or random intervals. If Recruitment Option #2 or #3 is selected, you will be prompted for this multiplication factor. For Recruitment Option #2, you will also be prompted for the interval at which big year classes occur and the first year of a big year class. For Recruitment Option #3 you will be prompted for the average frequency with which big year classes occur. The probability of a big year class in any given year would thus be the inverse of this frequency.

Recruitment Options #4 and #5 select recruitment as random either with equal probability between a specified minimum and maximum (Option #4) or with varying probability distributed normally with a specified mean and standard deviation (Option #5).

Recruitment Options #6-9 select recruitment as a function of stock size, and factor in parental stock size indirectly by calculating reproductive potential for each parental age class. Recruitment at age 1 is calculated as the product of this potential egg deposition, and an egg-to-age-1 survival rate calculated from an input on the mortality rate screen (Input Option #4). In Recruitment Option #6, recruitment is thus calculated directly from reproductive potential. In Recruitment Options #7-9, a realized egg deposition is calculated from the potential egg deposition using the density dependent relationship indicated. Age 1 numbers are then calculated as the product of this realized egg deposition and the egg-to-age-1 survival rate.

Density-dependant relationships between reproductive potential and realized egg deposition include those described by Beverton-Holt, Ricker and Cushing.

The Reverton-Holt equation is

$$R = 1/(a + b/P)$$

where

R = actual egg deposition,
P = potential egg deposition, and
a,b = parameters describing the shape of the curve. If you select this equation, you will be prompted for "a" and "b".

The Ricker equation is

$$R = Pe^{a(1 - P/P_r)}$$

where

e = 2.718
a = a parameter describing the shape of the curve, and

Pr = replacement egg deposition at equilibrium.

You will be prompted for **"Pr"** and "a" if you select this option. See Ricker (1975) for a discussion of these functions and methods for estimating parameters.

The Cushing equation (Kimura et al. 1984) is

$$R = \text{Emax} (P \ / \ \text{Pmax})^c$$

where

    P = population size,
Emax = maximum egg deposition,
Pmax = population size at Emax, and
   c = a constant describing strength of relationship.

If you select this option, you will be prompted for **"Emax"**, **"Pmax"** , and **"c"**.

Input Screen #4 prompts for mortality rates. Two sources of mortality are allowed: natural and exploitation. If you selected a stock related Recruitment Option, you will be prompted for a mortality rate from egg to age 1. You have the following options for egg-to-age-l mortality:

1. CONSTANT.

2. RANDOM WITH EQUAL CHANCE OVER A SPECIFIED RANGE.

3. RANDOM NORMAL WITH A SPECIFIED MEAN AND VARIANCE.

You will be prompted for numbers appropriate for the option you select. You are also prompted for a series of natural mortalities for ages 1 and above. Enter the conditional annual rate. After each rate you will be asked for the maximum age to which it applies. The minimum age is 1 greater than the maximum for the previous entry. You will continue to be prompted until you enter the maximum age individuals may reach (but the maximum number of age-specific entries is 20). You may thus enter a mortality rate for all ages without having to type in a number for each, or you may choose to enter a number for each age. In addition, you are prompted for the minimum and maximum exploitable sizes, and the annual rate of exploitation. You may enter exploitation for up to 20, nonoverlapping size classes.

Input Screen #5 prompts for life history parameters related to calculations of length and weight at age and of reproductive potential. Included are parameters for a von Bertalanffy age-length equation (Linf, k, to), an exponential length-weight equation (coefficient and exponent) , an exponential length-fecundity equation (coefficient and exponent) , the age at which females first mature, the proportion of the population over the age of maturity that is female, and the proportion

of mature females that spawn in any year. You will be prompted for a series of proportions of females spawning in any year. After each entry you will be asked for the maximum age to which it applies. The minimum age is 1 greater than the previous entry except for the first entry where the minimum age is the age at which females first mature. You will continue to be prompted until you enter the maximum age individuals may reach (but the maximum number of entries is 20). You may thus enter a proportion for all ages without having to type in a proportion for each, or you may choose to enter a proportion for each age.

Input Screen #6 prompts for age-specific weighting factors that can be used to project the effect of the population on another component of the system (the weighted effect). Weighting factors are input for each age. You are also prompted for the expression of population size or growth that is to be weighted. Choices include number, biomass, and production.

Input Screen #7 prompts for sizes used in calculating an index of population size structure analagous to proportional stock density (PSD) (Anderson 1980). The index is calculated as the number of individuals within one pair of minimum and maximum sizes (the numerator) divided by the number within a second pair of minimum and maximum sizes (the denominator).

PROCESSING

Processing is based on a series of difference equations. Given a number of individuals at the start of the year, the sequence of events is reproduction, exploitation, and death from natural causes.

The age-specific numbers of individuals at the start of the first year of the simulation are an input. Age-specific numbers of individuals (Nx) after the first year are calculated by the equation

$$N_{x+1, t+1} = (N_{x, t})(S_x)$$

where

S_x = age-specific annual survival rate, and
t = year.

Age-specific annual survival is calculated as

$$S_x = 1 - (m_x + n_x - (m_x)(n_x))$$

where

m_x = exploitation (harvest mortality rate), and
n_x = conditional natural mortality rate.

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Biomass present in each age class (B_x) is estimated

$$B_{x,t} = (N_{x,t})(W_x)$$

where

W_x = age-specific weight (units same as those supplied in length-weight equation).

Age-specific weights are calculated with age-length and length-weight equations using input parameters

$$L_x = L_{inf}(1 - e^{-k(x - t_0)}) \text{ and}$$

$$W_x = (aw)(L_x^{bw})$$

where

L_x = length at age,
L_{inf} = von Bertalanffy equation length at infinity,
k = von Bertalanffy equation parameter,
t_0 = von Bertalanffy equation parameter,
aw = length-weight equation coefficient, and
bw = length-weight equation exponent.

Reproductive potential of each age class (P_x) at or above the age of female maturity is estimated by

$$P_{x,t} = (N_{x,t})(F_x)(pf)(ps_x)$$

where

F_x = age-specific fecundity of females,
pf = proportion of population that is female, and
ps_x = age-specific proportion of females that spawn in any year.

Fecundity is estimated by

$$F_x = (af)(L_x^{bf})$$

where

af = length-fecundity equation coefficient, and
bf = length-fecundity equation exponent.

The net reproductive potential of all ages in any given year is

$$P = Sum(P_x).$$

This is the number upon which stock-related recruitment functions, discussed in the Input section (Page 5), operate to calculate recruitment at age 1 (N_1).

All animals are harvested at one time. Harvest in number (catch) and weight (yield) from an age class are calculated by

$$Hx = (N_x)(m_x) \text{ and}$$

$$Y_x = (N_x)(m_x)(W_x)$$

where

Hx = age-specific numbers of individuals removed by exploitation, and
Y_x = age-specific weight of individuals removed by exploitation.

Annual production of any age class $(PD_{x,t})$ is calculated by

$$PD_{x,t} = ((N_{x+1,t+1} W_{x+1} + N_{x,t} W_x)/2)(\log W_{x+1} - \log W_x).$$

The weighted effect of any age class (E_x) is calculated by

$$Ex = (N_x)(WF_x)$$

where

WF_x = age-specific weighting factor.

OUTPUT

The Output Option Menu was listed on page 2. Simulation results in the form of tables, summary statistics, or graphs may be displayed from this menu. Examples of these outputs follow. You may get a hard copy of any of the output tables and summary information by pressing Shift+PrtXc when the desired information is displayed. You may get a hard copy of a plot by pressing P when the plot is displayed.

Output Option #1
(List Input Information)

This option lists a short summary of processes, starting numbers, and parameters upon which the current simulation is based. It also lists the name of the file containing this input information, the date, and the time. These lists may be printed and attached to simulation results for reference.

Output Option #2
(List Reproduction by Age)

LISTING OF AGE-SPECIFIC REPRODUCTION INFORMATION IN YEAR 8

AGE	LENG	WGT	NUM	FECUND	P FEM	P SPN	PER FISH	EGGS
1	76	4	10000	76	0.50	1.00	38	**0.3803E+06**
2	137	28	5000	137	0.50	1.00	69	**0.3432E+06**
3	191	79	2500	191	0.50	1.00	95	**0.2386E+06**
4	238	160	1250	238	0.50	1.00	119	**0.1487E+06**
5	279	266	900	279	0.50	1.00	140	**0.1256E+06**
6	315	392	648	315	0.50	1.00	158	**0.1021E+06**
7	347	532	467	347	0.50	1.00	173	**0.8091E+05**
8	375	680	336	375	0.50	1.00	187	**0.6291E+05**

TOTAL			21100.48				POTENTIAL	1482315
							REALIZED	1482315

where

$\quad$ LENG = length in units from age-length equation (L_x),
$\quad$ WGT = weight in units from length-weight equation (W_x),
$\quad$ NUM = number of individuals in population (N_x),
$\quad$ FECUND = fecundity of females in age class (F_x),
$\quad$ P FEM = proportion of population that is female (pf),
$\quad$ P SPN = proportion of females that spawn in any year (ps_x),
PER FISH = fecundity per individual in population $((F_x)(pf)(ps_x))$, and
$\quad$ EGGS = reproductive potential in age class (P).

Output Option #3
(List Population by Age)

LISTING OF AGE-SPECIFIC POPULATION INFORMATION IN YEAR 8

AGE	LENG	WGT	START	EXPL	NTRL	SURV	NEW	BIOMASS	PROD
0			1482315		0	1			
1	76	4	10000	0.00	0.50	0.500		42089	169926
2	137	28	5000	0.00	0.50	0.500	5000	138368	177032
3	191	79	2500	0.00	0.50	0.500	2500	198136	139752
4	238	160	1250	0.10	0.20	0.720	1250	199929	111938
5	279	266	900	0.10	0.20	0.720	900	239571	95802
6	315	392	648	0.10	0.20	0.720	648	254256	76673
7	347	532	467	0.10	0.20	0.720	467	248372	58493
8	375	680	336	0.10	0.20	0.000	336	228542	0
TOTAL			21100					15493E+02	829616

where

AGE = 0 refers to reproductive potential,
LENG = length in units from age-length equation (L_x),
WGT = weight in units from length-weight equation (W_x),
START = number of individuals at the start of the year $(N_{x,t})$,
EXPL = ex[ploitation or harvest mortality rate (mx),
NTRL = conditional natural mortality rate (n_x),
SURV = age-specific annual survival rate (S_x),
NEW = number of individuals surviving to the start of the next year from the previous age class $(N_{x,t+1})$,
BIOMASS = weight of all individuals at the start of the year $(B_{x,t})$, and
PROD = production of biomass by age class including individuals that die (PD_x).

```
                          Output Option #4
                 (List Harvest, Yield, and Effect by Age)
```

LISTING OF HARVEST, YIELD, AND EFFECT IN YEAR 8

AGE	LENG	WGT	START	EXPL	CATCH	YIELD	WT VAR	FACTOR	EFFECT
1	76	4	10000	0.00	0	0	0	0.00	0
2	137	28	5000	0.00	0	0	0	0.00	0
3	191	79	2500	0.00	0	0	0	0.00	0
4	238	160	1250	0.10	125	19993	0	0.00	0
5	279	266	900	0.10	90	23957	0	0.00	0
6	315	392	648	0.10	65	25426	0	0.00	0
7	347	532	467	0.10	47	24837	0	0.00	0
8	375	680	336	0.10	34	22854	0	0.00	0
TOTAL			21100		360	117067			0

where

$\qquad$ LENG = length in units from age-length equation (L_x),
$\qquad$ WGT = weight in units from length-weight equation (W_x),
$\qquad$ START = number of individuals at the start of the year $(N_{x,t})$,
$\qquad$ EXPL = exploitation or harvest mortality rate (m_x),
$\qquad$ CATCH = harvest in numbers (H_x),
$\qquad$ YIELD = harvest in weight (Y_x),
WT VAR = variable weighted by FACTOR to calculate EFFECT,
FACTOR = age-specific weighting factor (WF_x), and
EFFECT = age-specific weighted effect (E_x).

SUMMARY OF ANNUAL POPULATION INFORMATION BY YEAR

YEAR	NUM	BIOM	REPRO	RECRUT	CATCH	YIELD	HARNUM	PROD	EFFECT	PSD
1	10000	4E+04	38E+04	10000	0	0E+00	0	2E+05	0E+00	0
2	15000	2E+05	72E+04	10000	0	0E+00	0	4E+05	0E+00	0
3	17500	4E+05	96E+04	10000	0	0E+00	0	5E+05	0E+00	0
4	18750	6E+05	11E+05	10000	125	200E+02	1250	6E+05	0E+00	0
5	19650	8E+05	12E+05	10000	215	439E+02	2150	7E+05	0E+00	0
6	20298	1E+06	13E+05	10000	280	694E+02	2798	8E+05	0E+00	0
7	20765	1E+06	14E+05	10000	326	942E+02	3265	8E+05	0E+00	0
8	21100	2E+06	15E+05	10000	360	117E+03	3600	8E+05	0E+00	0

where

NUM = total number of individuals in population (Sum N_x),
BIOM = total weight of all individuals in population (Sum B_x),
REPRO = realized egg deposition of all ages (R),
RECRUT = number of age 1 individuals (N_1),
CATCH = total numbers of inividuals harvested (Sum H_x),
YIELD = total weight of individuals harvested (Sum Y_x),
HARNUM = number of individuals in the harvestable size range (should be proportional to catch per unit effort in the fishery),
PROD = total production of biomass (Sum PD_x),
EFFECT = total effect of population weighted by age, and
PSD = size structure index (relative numbers of individuals in 2 size classes).

Output Option #6
(Calculate Summary Statistics for Population Over Time)

Summary statistics include mean, standard deviation, minimum, and maximum for annual summary variables selected from a list. The same variables displayed in Output Option #5 may be selected. Statistics are calculated over a range of years ending with the last year of the simulation. You also have the option of beginning at a year greater than 1 if you wish to allow a population to reach some equilibrium.

Output Option #7
(Plot Selected Variables)

You may plot yearly totals versus time, yearly totals versus each other, age-specific results in the last year of the simulation versus age, or age-specific results versus each other. When you choose this option, you are prompted to select age-specific or year-specific results. Variables that can be plotted for each option are displayed once you make your selection. You must enter variables for x and y axes. X-axis variables are automatically sorted from minimum to maximum. **Plotable** variables and definitions correspond with those listed in tables. The plot is automatically scaled so that the plot fills the Y-axis. You may print graphs by pressing P after the plot is drawn on the screen. (This option was programmed for an IBM graphics printer and may not work on other printers.)

Output Option #8
(Write By-Age Results to File)

This option writes age-specific results in the last year of the simulation to 'a data file on diskette. These results are then available for other applications such as plotting with graphics software. When this option is selected, you are prompted for a name for the file in which results are saved. You may enter a name up to 8 characters long or accept the default name of BYAGE. MOCPOP will add the extension ,DAT to whatever name you select. All age-specific variables included in tables listed by Output Options #2-4 will be written to the file and the first line in the file will contain variable names.

Output Option #9
(Write By-Year Results to File)

This option writes year-specific results to a data file on diskette, These results are then available for other applications such as plotting with graphics software. When this option is selected, you are prompted for a name for the file in which results are saved. You may enter a name up to 8 characters long or accept the default name of BYYEAR. MOCPOP will add the extension .DAT to whatever name you select. All year-specific variables included in the table listed by Output

Option #5 will be written to the file and the first line in the file will contain variable names.

Output Option #10
(Continue Present Simulation With New Parameters)

This option returns you to the Run Options Menu so that you may extend the current simulation for more years. You may select Run Option #3 to double the number of years in the simulation or you may change inputs by selecting Run Option #2 and using the Edit Options Submenu. Two possibilities exist for restarting the simulation after edits have been made. You may run directly from the Edit Options Submenu by selecting Edit Option #9 (Run) in which case the default input file will not be updated with any changes you have made. You may also run by selecting Edit Option #8 (Return to Run Option Menu), followed by Run Option #3 (Run Existing Model). Restarting the simulation from the Run Option Menu rather than from the Edit Option Menu will update the default input file with current values for all inputs including age-specific numbers in the last year of the simulation you are continuing.

EXAMPLE APPLICATIONS

Problem #1--Yield

Estimate yield at 10% exploitation for a population with the following characteristics:

1. Maximum age, 8.

2. Recruitment constant at 10000 age 1 individuals.

3. Natural mortality: age 1 through age 3, 50% per year: age 4 through age 8, 20% per year.

4. Harvestable size range, 200-400 mm.

5. von Bertalanffy age-length(mm) equation coefficients:
    $L_{inf} = 571$; $k = 0.132$: to = -0.083.

6. Length(mm)-weight(gm) equation coefficients:
    intercept = 0.0000042; slope = 3.19.

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Start MOCPOP. MOCPOP automatically advances through input parameters as you type a value for each and press Enter. Select Run Option #l (Build a New Model) from the Run Option Menu by typing 1 after the question mark and pressing Enter. You are then prompted for a name for the file in which inputs will be saved. Name the new model "YIELD" by typing YIELD and pressing Enter.

```
                              RUN OPTION MENU


     (1) BUILD A NEW MODEL

     (2) EDIT SELECTED INPUTS IN AN EXISTING MODEL

     (3) RUN EXISTING MODEL WITH DEFAULT OR EDITED INPUTS



     SELECT RUN OPTION [2]: ? 1

     NAME CURRENT VERSION []            ? YIELD
```

Next set years to run at 8 on Input Screen #l. Type 8, press Enter.

```
     HOW MANY YEARS DO YOU WANT TO RUN IN THIS SIMULATION [ 0 ]

     ? 8
```

Set maximum age at 8 on Input Screen #2. Type and enter 10000 for age 1 and 0 for ages 2-8. Remember, you may press Enter to accept the default value displayed in brackets or you may introduce a new value.

```
                    MAXIMUM AGE AND STARTING POPULATION SIZE

        HOW OLD DO INDIVIDUALS GET [ 0 ]      ? 8

        INPUT AGE-SPECIFIC NUMBERS OF INDIVIDUALS IN THE POPULATION
        YOU WILL BE PROMPTED FOR  8 AGE CLASSES

        AGE -  1  [ 0 ]              ? 10000
        AGE =  2  [ 0 ]              ?
        AGE =  3  [ 0 ]              ?
        AGE =  4  [ 0 ]              ?
        AGE =  5  [ 0 ]              ?
        AGE =  6  [ 0 ]              ?
        AGE =  7  [ 0 ]              ?
        AGE-   8  [ 0 ]              ?
```

Select Recruitment Option #1 on Input Screen #3 to fix annual recruitment at 10000.

```
                            RECRUITMENT

        CHOOSE A RECRUITMENT MECHANISM: [ 0 ]      ? 1

            1 = CONSTANT AT NUMBER ENTERED AS AGE 1 ABOVE
            2 - CONSTANT AT AGE 1 INPUT EXCEPT FOR BIG YEAR CLASSES AT FIXED INT
            3 - CONSTANT AT AGE 1 INPUT EXCEPT FOR BIG YEAR CLASSES AT RAND INT
            4 - RANDOM WITH EQUAL CHANCE OVER A SPECIFIED RANGE
            5 - RANDOM NORMAL WITH SPECIFIED MEAN AND STANDARD DEVIATION
            6 - STOCK RELATED - PROPORTIONAL TO REPRODUCTIVE POTENTIAL
            7 = STOCK RELATED = BEVERTON-HOLT RELATIONSHIP
            8 - STOCK  RELATED - RICKER  RELATIONSHIP
            9 = STOCK RELATED - CUSHING  RELATIONSHIP
```

Type 0.5 and press Enter for the first natural mortality rate on Input Screen #4. Type 3 and press Enter when prompted for the upper age. This sets natural mortality for ages 1 to 3 at 50% annually. To set mortality of age 4 to 8 individuals at 20%, type and enter 0.2 and 8 where prompted.

To set exploitation at 10% for a specified size range, type and enter size class, 1; minimum size, 200; maximum size, 400; and rate 0.1. Size units may be anything desired but you must be consistent. For instance if you use millimeters here you must supply length-weight equation coefficients also based on millimeters.

```
                          MORTALITY

INPUT CONDITIONAL NATURAL MORTALITY RATE(S) & UPPER AGE(S) TO WHICH THEY APPLY
YOU WILL BE PROMPTED UNTIL YOU INDICATE THE MAXIMUM AGE [ 8 ] IN POPULATION

        RATE [ 0 ]    ? 0.5            UPPER AGE [ 0 ]     ? 3
        RATE [ 0 ]    ? 0.2            UPPER AGE [ 0 ]     ? 8

INPUT EXPLOITED SIZE RENGE(S) AND EXPLOITATION RATE(S)

    ROW MANY SIZE CLASSES DO YOU INTEDN TO ENTR [ 0 ]     ? 1

    MIN SIZE [ 0 ]   ? 200     MAX SIZE [ 0 ]   ? 400    RATE [ 0 ]  ? 0.1
```

Now type and enter parameters for age-length and length-weight equations as indicated on Input Screen #5. This concludes the inputs necessary to solve the yield problem, but MOCPOP will continue to prompt you for additional inputs related to reproduction. These inputs are not used in this example but would **be needed if recruitment was a function** of **stock size** Enter arbitrarily selected values of 1 for **age** of maturity of females, 0.5 for proportion of population that is female, 1 for proportion of females that spawn in any year and 8 for upper **age** to which proportion applies.

```
                      LIFE   HISTORY   PARAMETERS

INPUT AGE-LENGTH EQUATION PARAMETERS (VON BERTALANFFY EQUATION):

   L-INFINITY [ 0 ]    ? 571  K [O]   ? 0.132    T-ZERO [ 0 ]   ? -0.083

LENGTH-WEIGHT EQUATION PARAMETERS (W = A . L ^ B0

        A [ 0 ]           ? 0.0000042 B [ 0 ]      ? 3.19

LENGTH-FECUNDITY EQUATION PARAMTERS (F = A . L ^ B)

        A [ 0 ]       ? 1              B [ 0 ]:  ? 1

INDICATE AGE OF MATURITY OF FEMALES [ 0 ]    ? 1

INDICATE PROP OF POPULATION OVER AGE 1 THAT IS FEMALE [ 0 ]       ? 0.5

INPUT PROP OF FEMALES THAT SPAWN IN ANY YEAR & UPPER AGES TO WHICH THEY APPLY
YOU WILL BE PROMTED UNTIL YOU INDICATE THE MAXIMUM AGE [ 8 ] IN POP

          PROP [ 0 ]    ? 1              UPPER ACE [ 0 ]     ? 8
```

You will also be prompted for information used to calculate weighted effects and a size structure index. This information is not needed to solve the yield problem, so accept defaults. After you have completed inputs, the model will automatically run the simulation you indicated and display the output options menu when done.

Instead of using the Build a New Model Option (#1), you may choose to enter inputs **by** using the Edit Selected Inputs Option (#2) of the Run Option Menu. That way you don't have to deal with inputs, such as weighted effect and PSD, which don't matter in this example and you can go back and change inputs you've already passed.

You will find the answer to this yield problem under Output Option #4 (List Harvest, Yield, and Effect by Age). Yield for this example is 117,067 gm. The example output tables shown on pages 10-13, correspond to this simulation.

Problem #2--Uncertainty

Estimate the range over which a population may vary as a result of variable recruitment. Use inputs as in Problem #l (page 15) except set recruitment to include big year classes that occur every 4 years on the average and are 3 times greater than normal.

Start MOCPOP and select Run Option #2 to begin entering inputs. When prompted for the name of the input file to edit, press Enter to accept the displayed default (YIELD). When prompted for a name for the current version, type UNCERT and press Enter.

```
                          RUN  OPTION MENU

   (1) BUILD A NEW MODEL

   (2) EDIT SELECTED INPUTS IN AN EXISTING MODEL

   (3) RUN EXISTING MODEL WITH DEFAULT OR EDITED INPUTS


   SELECT RUN OPTION (2): ?


   SELECT A MODEL FROM THE FOLLOWING LIST [YIELD]          ?

   TEST     YIELD

   NAME CURRENT VERSION [YEILD]       ? UNCERT
```

The Edit Options Submenu is displayed after you enter a new file name. First edit years to run by typing 1 and pressing Enter.

```
                       EDIT OPTION SUBMENU

   (1) YEARS TO RUN

   (2) MAXIMUM AGE AND STARTING POPULATION SIZE

   (3) RECRUITMENT

   (4) MORTALITY

   (5) LIFE HISTORY PARAMETERS

   (6) AGE SPECIFIC WEIGHTING FACTORS

   (7) AGE STRUCTURE INDEX

   (8) RETURN TO RUN OPTION MENU

   (9) RUN

   SELECT INPUTS TO BE EDITED [9]:    7 1
```

Set years to run at a large number, for instance 100.

```
HOW MANY YEARS DO YOU WANT TO RUN IN THIS SIMULATION [ 8 ]

? 100
```

After you complete entries on each screen, you are automatically returned to the Edit Options Submenu. You may then sequentially edit desired inputs by entering the appropriate option number. Next edit recruitment inputs by selecting Edit Option #3 and Recruitment Option #3* Indicate relative frequency and size of big year classes.

```
                           RECRUITMENT

CHOOSE A RECRUITMENT MECHANISM: [ 1 ]          ? 3

      1 = CONSTANT AT NUMBER ENTERED AS AGE 1 ABOVE
      2 = CONSTANT AT AGE 1 INPUT EXCEPT FOR BIG YEAR CLASSES A? FIXED INT
      3 - CONSTANT  AT AGE 1 INPUT EXCEPT FOR BIG YEAR CLASSES AT RAND INT
      4 - RANDOM WITH EQUAL CHANCE OVER A SPECIFIED RANGE
      5 - RANDOM NORMAL WITH SPECIFIED MEAN AND STANDARD DEVIATION
      6 - STOCK RELATED - PROPORTIONAL TO REPRODUCTIVE POTENTIAL
      7 - STOCK RELATED - BEVERTON-HOLT RELATIONSHIP
      8 = STOCK RELATED - RICKER RELATIONSHIP
      9 = STOCK RELATED - CUSHING  RELATIONSHIP

INDICATE FREQUENCY WITH WHICH BIG YEAR CLASSES OCCUR ON THE AVG [ 0    ]? 4

INDICATE HOW MANY TIMES LARGER THAN AVG BIG YEAR CLASSES ARE [ 0 ):   ? 3
```

Run the simulation by entering Option #9 in the Edit Options Submenu. After doing so, you might wish to plot numbers versus years to examine the pattern of variation. Select Output Option #7 and indicate year-specific results, an x-axis variable of "YEAR", a y-axis variable of "NUM", and a monitor resolution of "1".

```
                    PLOT SELECTED VARIABLES

SELECT THE TYPE OF RESULTS YOU WANT TO PLOT [1]          ?

                (1)  YEAR-SPECIFIC
                (2)  AGE-SPECIFIC

YOU HAVE A CHOICE OF THE FOLLOWING VARIABLES:

     Y E A R  NUM     BIOM    RSPRO  RECRUT  CATCH
     YIELD  HARNUM  PROD    WTEFF  PSD     EGGSRV

     SELECT X-AXIS VARIABLE (YEAR]: ?

     SELECT Y-AXIS VARIABLE [NUM]: ?

INDICATE NOMITOR RESOLUTION (1=200x360 2=720x348) [1]:?
```

A figure similar to the following is displayed. Figures will vary because the years when big year classes occur are randomly selected.
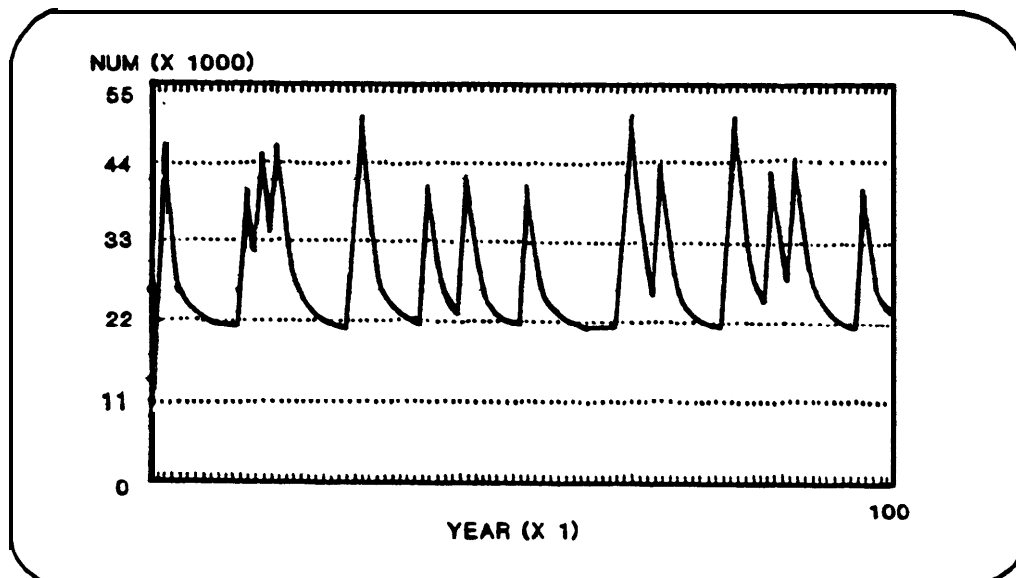
You see that numbers started low and increased as a population containing all age classes was built. After that, the population fluctuated as big year classes occurred and moved through the population.

You may also use the Summary Statistics Option (#6) in the Output Options Menu to calculate the mean, standard deviation, and range over which population numbers varied. In this example, we start with year 9 to avoid including years before all age classes were represented in the population.

```
              SUMMARY  STATISTICS FOR POPULATION THROUGH TIME

 SELECT FROM THE LIST BELOW THE VARIABLE
 FOR WHICH YOU WANT SUMMARY STATISTICS [NUM]:    ?

    NUM      BIOM      REPRO     RECRUT    PROD
    CATCH    YIELD     HARNUM    WTEFF     PSD      EGGSRV


 INCLUDE ALL YEARS STARTING WITH [1]:? 9


              FOR VARIABLE NUM              MEAN =  28433.01
              BETWEEN YEARS  9  AND  100    SD =   8451.068
                                            MIN =  21100.48
                                            MAX-   51100.48



 CALCULATE ANOTHER (N) ?
```

Problem #3 Response- Time

Estimate how quickly a population will recover after a reduction of 50%. Assume a Beverton-Holt stock-recruitment relationship of low to moderate resilience (A = 0.2) (See Ricker (1975), page 292). Assume no age structure, weights and lengths as in problems 1 and 2, fecundity equal to length, and a sex ratio of 1:1 with all females spawning.

This situation approximates a simple stock-recruitment-type model, but instead of calculating a progeny stock size directly from parental stock size, MOCPOP works by calculating a reproductive potential for parental stock, then multiplying that potential by an egg-to-adult survival rate. You must supply reproductive potential at equilibrium (alpha in the Beaverton-Holt equation) and egg-to-adult (age 1) mortality to run this simulation. You can use MOCPOP to simplify calculation of these numbers by first running a one year simulation to calculate reproductive potential, then solving for the mortality rate that will give you the starting stock size you supplied.

Start the model and select Run Option #2 to begin entering inputs. When prompted for the name of the input file to edit, press Enter to accept the displayed default (UNCERT). When prompted for a name for the current version, type RESPTIME and press Enter. The Edit Options Submenu is displayed after you enter a new file name. First edit years to run after typing 1 and pressing Enter.   Set years to run to 1.

```
HOW MANY YEARS DO YOU WANT TO RUN IN THIS SIHULATION [ 100 ]

? 1
```

Next choose Edit Option #2 and enter a maximum age of 1 and a starting population of 10000.

```
                    MAXIMUM AGE AND STARTING  POPULATION  SIZE

HOW OLD DO INDIVIDUALS GET [ 8 ]      ? 1

INPUT AGE-SPECIFIC NUMBERS OF INDIVIDUALS IN THE POPULATION
YOU WILL BE PROMPTED FOR  1  AGE CLASSES

AGE - 1  [ 10000 ]              ?
```

Choose Edit Option #3 and select the constant recruitment option (#1).

```
                              RECRUITMENT

CHOOSE A RECRUITMENT MECHANISM: [ 3 ]        ? 1

     1 = CONSTANT AT NUMBER ENTERED AS AGE 1 ABOVE
     2 = CONSTANT AT AGE 1 INPUT EXCEPT FOR BIG YEAR CLASSES AT FIXED INT
     3 - CONSTANT AT AGE 1 INPUT EXCEPT FOR BIG YEAR CLASSES AT RAND INT
     4 = RANDOM  WITH EQUAL CHANCE  OVER  A SPECIFIED RANGE
     5 - RANDOM NORMAL WITH SPECIFIED MEAN AND STANDARD DEVIATION
     6 = STOCK RELATED - PROPORTIONAL TO REPRODUCTIVE POTENTIAL
     7 - STOCK RELATED - BEVERTON-HOLT RELATIONSHIP
     8 = STOCK RELATED - RICKER RELATIONSHIP
     9 - STOCK RELATED - CUSHING RELATIONSHIP
```

Choose Edit Option #5 and edit life history parameters as indicated.

```
                    LIFE HISTORY PARAMETERS

INPUT AGE-LENGTH EQUATION PARAMETERS (von Bertalanffy EQUATION):

   L-INFINITY [ 571 ] ?     K [ .132 ]?          T-ZERO [-.083 ]?

LENGTH-WEIGHT EQUATION PARAMETERS (W = A * L ^ B)

        A [ .0000042 ]    ?           B [ 3.19 ] ?

LENGTH-FECUNDITY EQUATION PARAMETERS (F = A . L ^ B)

        A [ 1 ]       ?              B [ 1 ]: ?

INDICATE AGE OF MATURITY OF FEMALES [ 1 ]   ?

INDICATE  PROP  OF POPULATION OVER AGE 1  THAT  IS  FEMALE [ .5 ]      ?

INPUT PROP OF FEMALES THAT SPAWN IN ANY YEAR & UPPER ACES TO WHICH THEY APPLY
YOU WILL BE PROMPTED UNTIL YOU INDICATE THE MAXIMUM AGE [ 1 ] IN POP

        PROP [ 1 ]    ?               UPPER AGE [ 8 ]    ? 1
```

For the present you may ignore inputs for mortality as these are not needed in the 1 year simulation. After running the simulation (Edit Option #9), inspect the age-specific reproduction information screen (Output Option #2).

```
          LISTING OF AGE-SPECIFIC REPRODUCTION INFORMATION IN YEAR 1
    ----------------------------------------------------------------------
    AGE  LENG   WGT      NUM       FECUND  P FEM P SPN    PER FISH    EGGS
    ----------------------------------------------------------------------

     1    36    4      10000         76 0.50 1.00         3  8   0.3803E+06
          TOTAL         10000                                    380308
                                                        REALIZED  380308
    ----------------------------------------------------------------------




               STRIKE ANY KEY TO RETURN TO OUTPUT OPTIONS MENU
```

The reproductive potential of the population you input is 380,308.

Now return to the Run Options Menu to run a new simulation to determine how long it will take for the population to recover from a 50% reduction. Do so by entering Output Option #11. Select Run Option #2 to begin entering inputs. When prompted for the name of the input file to edit, press Enter to accept the displayed default (RESPTIME). When prompted for a name for the current version, press Enter to continue saving changes in the file RESPTIME. The Edit Options Submenu is displayed after you enter a new file name. First increase the number of years to run to 50 (Edit Option #1).

```
    HOW MANY YEARS DO YOU WANT TO RUN IN THIS SIMULATION [ 1 ]

    ?  50
```

Next, reduce starting population size to 5000 (Edit Option #2).

```
                    MAXIMUM AGE AND STARTING POPULATION SIZE

HOW OLD DO INDIVIDUALS GET ! 1 ]       ?

INPUT AGE-SPECIFIC NUMBERS OF INDIVIDUALS IN THE POPULATION
YOU WILL BE PROMPTED FOR 1 AGE CLASSES

AGE = 1  [ 10000 ]             ? 5000
```

Indicate that recruitment (Edit Option #3) is based on a Beverton-Bolt equation (Recruitment Option #7) and supply parameters.

```
                           RECRUITMENT

CHOOSE A RECRUITMENT MECHANISM: [ 1 ]        ? 7

     1 - CONSTANT AT NUMBER ENTERED AS AGE 1 ABOVE
     2 = CONSTANT AT AGE 1 INPUT EXCEPT FOR BIG YEAR CLASSES AT FIXED INT
     3 - CONSTANT AT AGE 1 INPUT EXCEPT FOR BIG YEAR CLASSES AT RAND INT
     4 = RANDOM WITH EQUAL CHANCE OVER A SPECIFIED RANGE
     5 - RANDOM NORMAL WITH SPECIFIED MEAN AND STANDARD DEVIATION
     6 - STOCK RELATED - PROPORTIONAL TO REPRODUCTIVE POTENTIAL
     7 - STOCK RELATED - BEVERTON-HOLT RELATIONSHIP
     8 - STOCK RELATED - RICKER RELATIONSHIP
     9 - STOCK RELATED - CUSHING RELATIONSHIP

INPUT ALPHA FOR BEVERTON-HOLT EQN [ 0 ]:      ? 5.259E-07

INPUT BETA FOR BEVERTON-HOLT EQN [ 0 ]:       ? 0.8
```

Parameters are calculated:

$$\text{Alpha} = \lambda/P_r = 0.2/380308 = 5.259E\text{-}07$$
$$\text{Beta} = 1 - A = 1 - 0.2 = 0.8$$

Lastly, edit mortality inputs (Edit Option Y4) and input the egg mortality rate.

```
                              MORTALITY
SELECT AN OPTION FOR NATURAL MORTALITY RATE FROM EGG TO AGB 1 [ 0 ]      ? 1

      ( 1) CONSTANT
      (2) RANDOM WITH EQUAL CHANCE OVER A SPECIFIED RANGE
      (3) RANDOM NORMAL WITH SPECIFIED MEAN & STANDARD DEVIATION

      INPUT CONSTANT EGG TO AGE 1 MORTALITY [ 0 ]       ? 0.973796

INPUT CONDITIONAL NATURAL MORTALITY RATE(S) & UPPER AGE(S) TO WHICH THEY APPLY
YOU, WILL BE PROMPTED UNTIL YOU INDICATE THE MAXIMUM AGE [ 1 ] IN POPULATXON

      RATE [ .5 ]   ?                      UPPER AGE [ 3 ]      ? 1

INPUT EXPLOITED SIZE RANGE(S) AND EXPLOITATION RATE(S)

      HOW MANY SIZE CLASSES DO YOU INTEND TO ENTER [ 1 ]     ?

      WIN SIZE [ 200 ] 7           MAX SIZE [ 400 ] ?        RATE [ -1 ] 0
```

This rate is calculated as

$$\text{Rate} = 1 - 10000/380308 = 0.973796$$

You are also prompted for natural and harvest mortality rates on the mortality screen, but these numbers are not used in our simulation because no fish live past age 1. Age 1 mortality is automatically set to 100% by MOCPOP regardless of what you enter here because 1 is the maximum age.

You are now ready to run the simulation. Do so by typing "9" and pressing Enter. When the simulation is complete and the Output Options Menu is displayed, plot numbers versus years. Do so by selecting Output Option #7, indicating year-specific results, entering an x-axis variable of "YEAR", entering a y-axis variable of "NUM", and entering a monitor resolution of "1. "

You see approximately 25 years are required for our population to recover to equilibrium levels.
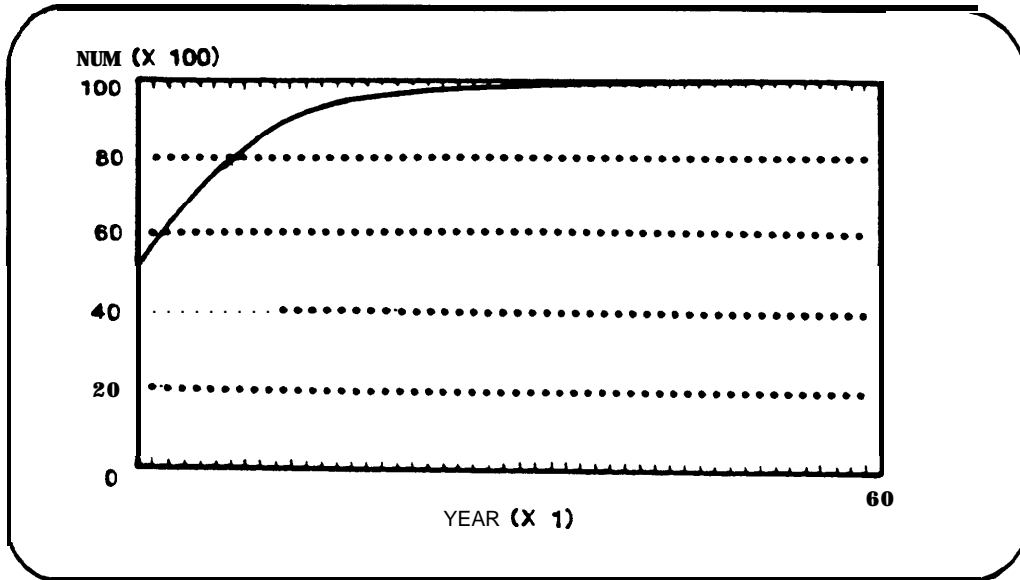
COPIES AND BUGS

A copy of MOCPOP may be obtained by sending a diskette and self-addressed mailer with stamp to the author. MOCPOP may be copied and distributed freely and no person or organization is authorized to charge any fee or price for MOCPOP. MOCPOP includes the following files

1.   MOCPOP10.EXE: the executable program file.

2.   **MOCPOP10.LIB:** a library file containing introductory text.

3.   **MOCPOP10.DOC:** an ASCII file containing a copy of the documentation.

4.   **MPTEST.MPK:** a file containing example input data.

MOCPOP is distributed without warranty. If you find a bug, I will repair it in future versions if you notify me in writing.

REFERENCES

Anderson, R.O. 1980. Proportional Stock Density (PSD) and Relative Weight (Wr) : interpretive indices for fish populations and communities. Pages 27-33 in S. Gloss and B. Shupp, editors. Proceedings of the First Annual Workshop, Practical Fisheries Management: More with less in the 1980's. American Fisheries Society, New York Chapter.

Kimura, D.K. J.W. Balsiger, and D.H. Into. 1984. Generalized stock reduction analysis. Canadian Journal of Fisheries and Aquatic Sciences 41:1325-1333.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Taylor, M.W. 1981. A generalized inland fishery simulator for management biologists. North American Journal of Fisheries Management 1:60-72.

Vaughan, D.S., R.M. Yoshiyama, J.E. Breck, and D.L. DeAngelis. 1982. Review and analysis of existing modeling approaches for assessing population-level effects of multiple stresses on fish and shellfish. Oak Ridge National Laboratory, Environmental Sciences Division, Publication 1979.

Walters, C.J. 1969. A generalized computer simulation model for fish population studies. Transactions of the American Fisheries Society 98:505-512.

User's Guide for PRSPRED: A Model of Predation by Resident Fish
on Juvenile Salmonids in a Columbia River Reservoir

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Production of salmon *Oncorhynchus* spp. and steelhead *Salmo gairdneri* in the Columbia River system is drastically reduced by mortality during outmigration (Ebel 1977). Predation by resident fish species accounts for much of the previously unexplained mortality in John Day Reservoir (Rieman et al. 1988). Predation mortality is dynamic, varying in time and space.

RESPRED incorporates factors we know or suspect regulate predation mortality of juvenile salmonids in John Day Reservoir. This model was written to organize our understanding of processes that regulate mortality of salmonids, to predict changes in predation over time with normal variation of the regulating factors, and to evaluate alternative strategies for reducing predation (Beamesderfer et al. 1988). Programming was built around processing to aide manipulation of input population parameters and inspection of simulation results.

MODEL DESCRIPTIOIW

The model consists of a system of difference equations solved at daily intervals for a 150-day period that corresponds to the April through August period of salmonid outmigration. In the model, John Day Reservoir is divided into two areas: the tailrace immediately below McNary Dam at the upper end of the reservoir (the boat-restricted-zone, or BRZ), and the remaining body of the reservoir (Figure 1).

Number of predators in the entire reservoir is an input. The reservoir-wide predator population is reduced during the season by a daily rate of mortality (Table 1, Equation 1). Predators from the entire-reservoir population are apportioned each day into areas (Figure 2) Predator distribution may be input directly, varied by time of year (Table 1, Equations 2 and 5), and/or scaled in response to number of prey in the BRZ to simulate the effects of a hypothetical numerical response (Equation 4) (Krebs 1985). The model also provides an option to apportion number of predators between active and inactive compartments in each area (Table 1, Equation 6). Activity proportions may be input directly or related to water discharge (flow).

Prey enter the reservoir at McNary Dam and pass through each area in sequence (Figure 2). Prey number may be input directly or generated as a normally distributed function of time (Equation 7). The number of prey in the reservoir is regulated by number entering and residence time (Table 1, Equation 8). Numbers entering the BRZ correspond to passage past McNary Dam. Residence time in the BRZ is ignored. Number of prey entering the reservoir body include those salmonids that pass McNary Dam which survive predation in the BRZ. Residence time in the reservoir is represented as an exponential decay function in which some proportion of the prey population left the reservoir daily. Days when 50% of a cohort of prey remained corresponded to an average passage time (Table 1, Equation 9). Residence time can be input directly or can be described as a
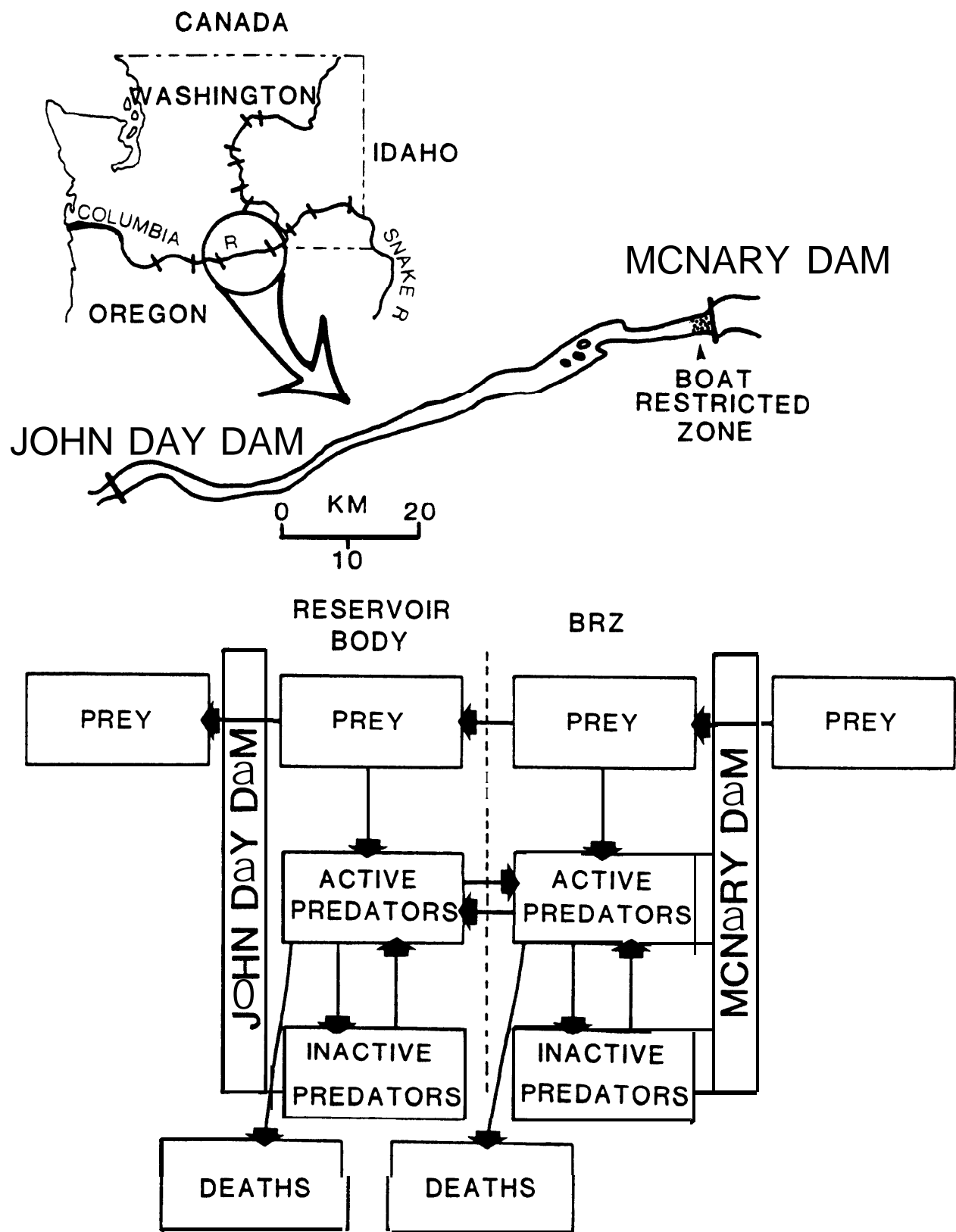
Figure 1. Conceptual model of predation by northern squawfish on juvenile salmonids in John Day Reservoir.

Table 1. Definitions of state and driving variables included in a model of predation in John Day Reservoir. **p1,...,p24** are parameters defined in Table **2.**

Variable	Definition	Equation Number
Pn(t)	Number of predators in population at time **t** $=$ **Pn(t-1) RDm(t-1)**	1
RDm(t)	Fraction of population that dies daily	
Pnl **(t)**	Number of predators in boat-restricted-zone $=$ **Pn(t) RBrz(t)**	
RBrz(t)	Fraction of predator population in BRZ	
RNr(t)	Proportion to adjust distribution for prey number (to approximate numerical response)	
Pn2 **(t)**	Number of predators in reservoir body $=$ **Pn(t) - Pn1(t)**	5
APni(t)	Number of predators in area **i (i** $=$ 1 is BRZ, **i** $=$ 2 is reservoir body) that are actively feeding $=$ **Pni(t) RAci(t)**	6
RAci(t)	Fraction of predator population in area **i** that is actively feeding.	
Jvl **(t)**	Number of juvenile salmonids in BRZ **(= DJv(t))**	
DJv(t)	Number of juvenile salmonids passing McNary Dam	
Jv2 **(t)**	Number of juvenile salmonids in reservoir body $=$ Jv2 (t-l) **- Jv2(t-1)/RTmE(t-1) - SC2(t-1) + DJv(t) - SC1(t)**	8
RTmE(t)	Exponential residence time for prey in the reservoir $=$ **RTm(t) / -Ln0.5**	9
RTm(t)	Average residence time (days)	
DFl(t)	Flow rate **(10^3 CFS)** at dam	
SC1(t)	Number of prey consumed by predators in BRZ $=$ **APn1(t) RCn1(t)**	12

Table 1. Continued.

Variable	Definition	Equation Number
$RCn1(t)$	Consumption rate of prey per predator in BRZ $= RCn_{max}(t)/(1 + p14\ e^{-p15\ Jv1(t)})$	13
$RCn_{max}(t)$	Maximum potential consumption rate (prey per predator per day)	
$DTp(t)$	Temperature (degrees centigrade) in reservoir at time t $= p21 + p22\ t$	15
$SC2(t)$	Number of prey consumed by predators in reservoir body $= APn2(t)\ RCn2(t)$	16
$RCn2(t)$	Consumption rate of prey per predator in reservoir body $= RCn_{max}(t)/(1 + p23\ e^{-p24\ Jv2(t)})$	17

Table 2. Definitions of parameters and values used in a model of predation in John Day Reservoir.

Reference equation number	Symbol of parameter	Description of parameter
3	p1	Intercept for proportion in BRZ
	p2	Slope for proportion in BRZ
18,19	p3	Change in proportion (+) with specified range in passage number
	p4	Minimum daily passage
	p5	Maximum daily passage
7	p6	Number of salmonids in run
	p7	Day of peak passage
	p8	Index of run duration (days in one standard deviation from day of peak passage)
10	p9	Intercept for residence time
	p10	Slope for residence time
11	p11	Maximum discharge at McNary Dam
	p12	Day of maximum discharge
	p13	Days in one standard deviation from day of maximum discharge
13	p14	Constant refering to intercept for consumption rate in BRZ
	p15	Constant refering to response rate to increasing prey for consumption rate in BRZ
14	p16	Coefficient for maximum potential consumption rate versus temperature
	p17	Coefficient for maximum potential consumption rate versus temperature
	p18	Coefficient for maximum potential consumption rate versus temperature
	p19	Coefficient for maximum potential consumption rate versus temperature
	p20	Coefficient for maximum potential consumption rate versus temperature
15	p21	Intercept for temperature
	P22	Slope for temperature

Table 2. Continued.

Reference equation number	Symbol of parameter	Description of parameter
17	p23	Constant refering to intercept for consumption rate in reservoir
	p24	Constant refering to response rate to increasing prey for consumption rate in reservoir
4	p25	Intercept for numerical response
	p26	Slope for numerical response
20	P27	Intercept for proportion active versus flow
	p28	Slope for proportion active versus flow
21,22	p29	Change in proportion ($\pm$) with specified range in flow
	p30	Minimum flow
	p31	Maximum flow
23	p32	Intercept in maximum potential consumption versus temperature
	P33	Slope in maximum potential consumption versus temperature
24	P34	Intercept in functional response response rate parameter versus temperature
	P35	Slope in functional response response rate parameter versus temperature
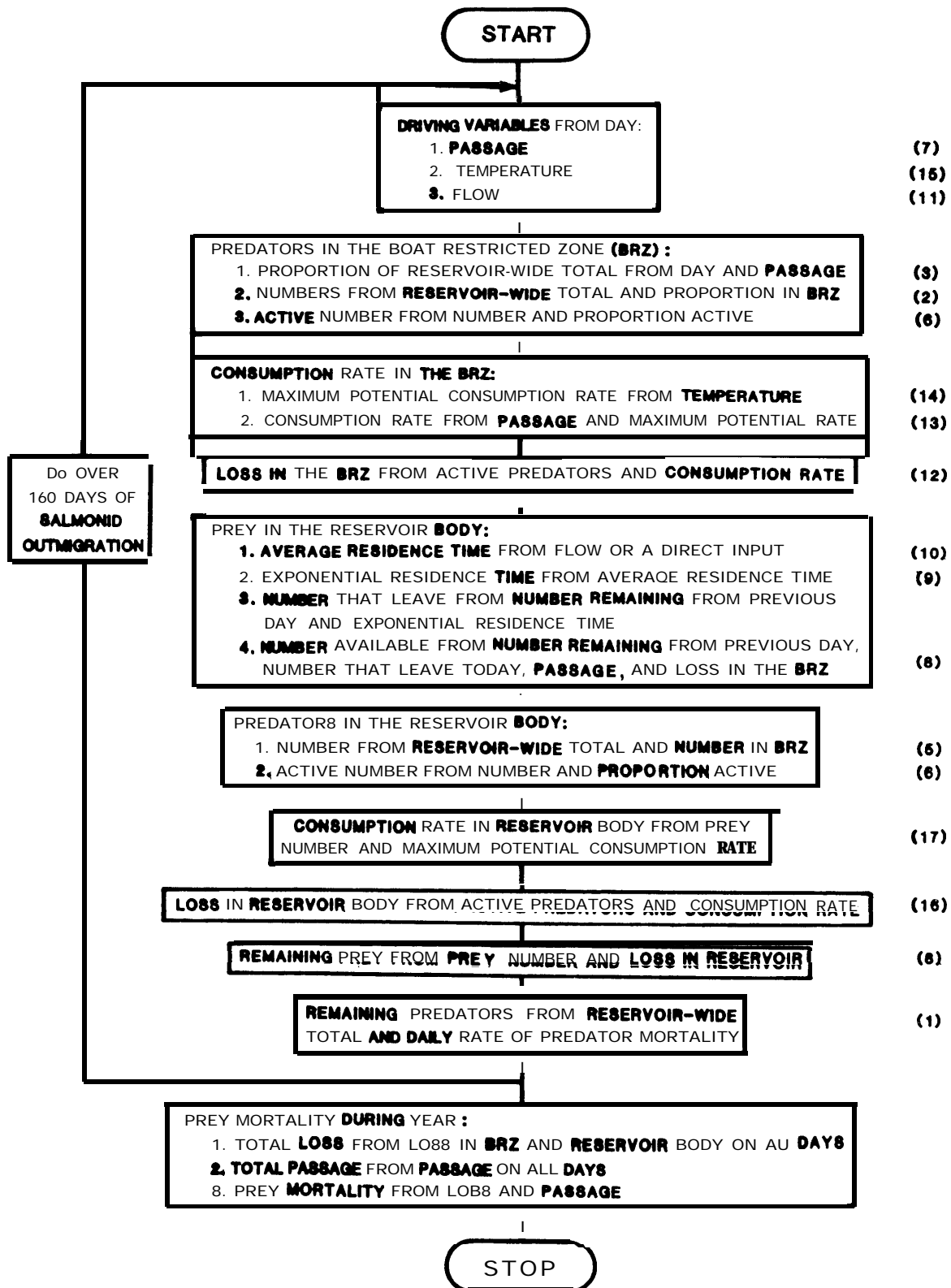
Figure 2. Sequence of calculations in model of predation in John Day Reservoir. Reference equation numbers from Table 1 are included in parentheses.

function of flow (Equation 10). Water discharge past McNary Dam may be input directly or described as a normal function of time (Equation 11).

Prey consumption rate per predator per day is modeled as a logistic function of prey number (Type III "functional response"). Consumption rate is related to passage number in the BRZ (Table 1, Equation 13) and number of prey calculated from passage and residence time in the reservoir (Table 1, Equation 17). Predation in the BRZ is thus assumed to be a lie-in-wait process where predators have one chance to capture a salmonid as it passes. Predation in the reservoir is simulated as a rover-predator process where prey are continuously exposed to predators until they pass from system.

Options are provided to incorporate effects of seasonally changing temperature on consumption rate by describing functional response equation parameters (Table 1, Equations 13 and **17))** as functions of temperature. The function relating temperature to the parameter describing maximum rate of consumption may be linear or a sixth degree polynomial (Equation 14). The function relating temperature to the parameter describing the rate of response to increasing prey number may be linear. Temperature may be input directly or described as a linear function of time (Equation **15).**

Loss of prey to predators is estimated in each area on each day as the product of number of active predators and daily consumption rate (Table 1, Equations 12 and 16). Mortality is estimated by dividing total loss to predators in a time period by the number of salmonids entering the reservoir in that time period.

HOW TO RUN RESPRED

To run RESPRED you must:

1. Boot machine with PC-DOS or MS-DOS.

2. Place diskette containing model in default drive.

3. Start the model (type RESPREDl after > prompt and press Enter) .

The program may be interrupted by pressing Control+Break or exited by selecting the Quit Option (#8) in the Output Options Menu (See page 3).

RESPRED is written in compiled Microsoft QuickBASIC v4.0 to run on IBM and IBM-compatible machines. Graphics require an IBM color graphics adaptor or functional equivalent. Hercules monochrome graphics cards are not supproted.

HOW RESPRED WORKS

RESPRED is organized into 3 parts. The input section prompts the user to supply initial state variables and parameters that describe conditions in the reservoir from April through August during the 150-day period of salmonid outmigration. The processing section calculates losses and mortality of the salmonid prey to a resident predator. The output sections displays the results of the simulation in tabular or graphical form.

Instead of re-entering inputs each time you use RESPRED, you may rerun a simulation with inputs entered previously or you may edit your earlier inputs and run a new simulation. Each time RESPRED is executed, it reads a data file containing inputs supplied in the previous run and updates the file with any changes you make in the current run. This file is called **RESPRED1.KEY.**

Execution of the program is controlled from two main menus and one submenu. The "Run Options Menu" is displayed when the program is started and controls the input process. Run Options include:

1. BUILD A NEW MODEL OR SEQUENTIALLY EDIT DEFAULT INPUTS.

2. EDIT SELECTED INPUTS IN AN EXISTING MODEL.

3. RUN EXISTING MODEL WITH DEFAULT OR EDITED INPUTS.

Run Option #1 steps through each input one at a time and starts the simulation when the last input is entered. Run Option #1 has no provision for going backward; you must press Ctrl+Break and restart if you make an entry error and all the inputs you entered in the current run are lost. Run Option #2 uses inputs from the last simulation but allows changes before the simulation starts. When you select the Edit Selected Inputs Option (Run Option #2), a list of inputs that may be changed is displayed in an "Edit Options Submenu". You select the desired inputs, make changes, and start the simulation from the "Edit Options Submenu'* (See page 4). Run Option #2 lets you go back and change inputs you've already passed by reselecting the same option from the menu. Run Option #3 immediately starts the simulation using inputs from the previous simulation which are contained in the default data file.

The "Output Options Menu" is displayed when the simulation is completed. Output Options include:

1. LIST SUMMARY OF INPUTS.

2. LIST SUMMARY OF RESULTS.

3. LIST SUMMARY OF RESULTS BY AREA.

4. LIST ENVIRONMENT AND PREDATOR INFORMATION BY DAY.

5. LIST JUVENILE SALMONID INFORMATION BY DAY.

6.   PLOT SELECTED VARIABLES.

7.   RETURN TO START FOR NEW SIMULATION.

8.   QUIT.

Examples of output generated by options are contained in the section on output.

INPUT

In the input section you are sequentially prompted to supply initial state variables and parameters that describe conditions that affecting mortality of juvenile salmonids to a resident predator during the 150-day period of salmonid outmigration. Default values for each input are read from the data file updated during the last simulation, and are displayed in brackets. Default values are also displayed for menu options to speed execution of the program. Defaults can be accepted by pressing Enter. Inappropriate numbers may not be accepted and you may have to enter a new number. Commas in numbers are not accepted. Decimal fractions may or may not be preceeded with a zero. All characters must be entered in capital letters. As appropriate inputs are entered, RESPRED automatically advances to the next input or moves to the next screen.

Inputs are organized into 5 categories, and each category corresponds to a screen in the input section. These screens are accessed in order by Option #1 in the Run Options Menu (build a new model) and are accessed selectively by Run Option #2 (edit selected inputs). Selection of Run Option #2 displays a listing of these categories in the Edit Options Submenu. Input screens-categories in order are:

'1.   PREDATOR ABUNDANCE AND DISTRIBUTION.

2.   PREDATOR ACTIVITY LEVELS.

3.   PREY - NUMBERS ENTERING AND RESIDENCE TIME.

4. TEMPERATURE AND FLOW.

5.   FUNCTIONAL RESPONSE:

Input Screen #1 (Predator Abundance and Distribution) prompts for the number of predators (Pn) in the reservoir at the start of the 150-day period of the salmonid outmigration, the fraction of predators that die each day (RDm), and the proportion of predators in the boat restricted zone (RBrz). You are prompted to select one of 4 options for how the proportion of predators in the BRZ is calculated

1.   CONSTANT.

2.   A FUNCTION OF TIME.

3.   A FUNCTION OF TIME AND PREY DENSITY.

4.   A FUNCTION OF TIME AND PREY DENSITY (REDUCTION KNOWN).

You are then prompted for inputs appropriate to your selection. For Option #l you are prompted for a proportion which is applied to each day. For Option #2 you are prompted for intercept (pl) and slope (p2) parameters in an equation that expresses the fraction of the predator population in the BRZ as a linear function of day (t)

$$RBrz(t) = pl + p2\ t. \tag{3}$$

For Option #3 you are prompted for the same parameters as for Option #2 but you are also prompted for intercept and slope parameters to calculate a proportion to adjust the fraction in the BRZ for prey number (RNr) .

$$RNr(t) = p25 + p26\ DJv(t) \tag{4}$$

This factor approximates a numerical response of predators into the BRZ in response to increased prey number (DJv) and is added to the RBrz calculated in Equation 3. Option #4 likewise calculates RBrz as a function of time and prey number but calculates intercept and slope parameters for you rather than making you input them directly. Parameters are calculted from a range of variation in the distribution fraction (plus or minus **p3**) over a range in prey numbers (low = p4, high = **p5)**.

$$p25 = -p3 - p4\ (2p3/(p5-p4))$$

$$p26 = 2p3/(p5 - p4)$$

Input Screen #2 (Predator Activity Levels) prompts for the fraction of predators in the BRZ (RAcl) and reservoir body (RAc2) that are actively feeding on salmonids. You are prompted to select one of four options for entering these active fractions

1.   CONSTANT.

2.   CONSTANT BUT MONTH SPECIFIC.

3.   A LINEAR FUNCTION OF FLOW.

4.   A LINEAR FUNCTION OF FLOW - REDUCTION KNOWN.

You are then prompted for inputs appropriate to your selection. For Option #l you are prompted for a proportion which is applied to each day. For Option #2 you are prompted for proportions for each month; April, May, June, July, and August. For Option #3 you are prompted for intercept **(p27)** and slope **(p28)** parameters in an equation that expresses the fraction of the predator population that is active as a linear function of flow.

$$RAci(t) = p27 + p28 \; DFl(t) \qquad (20)$$

Option #4 likewise calculates **RAci** as a function of flow but calculates intercept and slope parameters for you rather than making you input them directly. Parameters are calculated from a range of variation in the proportion active (plus or minus **p29)** over a range in flow (low = **p30,** high = **p31).**

$$p27 = -p29 - p30\,(2p29/\,(p31-p30))\qquad (21)$$

$$p28 = 2p29/\,(p31 -p30)\qquad (22)$$

Input Screen #3 (Prey – Numbers Entering and Residence Time) prompts for number of juvenile salmonids entering the reservoir and residence time. Prey numbers may be entered

1. AS A CONSTANT.

2. NORMALLY DISTRIBUTED AS A FUNCTION OF TIME.

You are prompted for inputs appropriate to your selection. For Option #1 you are prompted for a number which is applied to each day. For Option #2 you are prompted for the total number of salmonids in the run **(p6),** the day of 50% passage numbered from 1 on April 1 **(p7),** and the number of days in one standard deviation from the day of 50% passage **(p8).** Daily passage **(DJv)** is then calculated

$$DJv(t) = (p6/(2.5066 \; p7)) \; e^{-(p8 \, - \, t)\, \char94 \, 2/(2 \; p7 \, \char94 \, 2 \,)} \qquad (7)$$

Residence time may be entered

1. AS A CONSTANT.

2. AS A CURVILINEAR FUNCTION OF FLOW.

You are prompted for inputs appropriate to your selection. For Option #1 you are prompted for a number which is applied to each day. For Option #2 you are prompted for intercept **(p9)** and slope **(p10)** parameters in the flow-residence time equation

$$RTm(t) = 1 \; / \; (p9 + p10 \; DFl(t))\qquad (10)$$

Input Screen #4 (Temperature and Flow) prompts for temperature and flow inputs. Temperature may be entered

1. AS A CONSTANT.

2. AS A LINEAR FUNCTION OF TIME.

You are prompted for inputs appropriate to your selection. For Option #1 you are prompted for a temperature **(DTp** in degrees centigrade) which is applied to each day. For Option #2 you are

prompted for intercept **(p21)** and slope **(p22)** parameters in the time-temperature equation

$$DTp(t) = p21 + p22\ \mathbf{t.} \qquad\qquad\qquad ' \qquad (15)$$

Flow may be entered

1. AS A CONSTANT.

2. NORMALLY DISTRIBUTED AS A FUNCTION OF TIME.

You are prompted for inputs appropriate to your selection. For Option **#1** you are prompted for a flow (in cfs **x 10^3**) which is applied to each day. For Option 12 you are prompted for maximum daily discharge (pll), day of maximum discharge numbered from day 1 on April 1 **(p12),** and number of days in one standard deviation from the day of maximum discharge **(p13).** Flow **(DJv)** is then calculated for each day **(t)**

$$DFl(t) = p11\ e^{-(p12\ -\ t)\char`\^2/(2\ p13\char`\^2)} \qquad (11)$$

Input Screen **#5** (Functional Response) prompts for parameters in the functional response equations in the **BRZ** and the reservoir body. Functional response equation inputs include a maximum potential consumption rate (RCn_{max}), an intercept parameter **(p14** in BRZ, **p23** in reservoir body), and a response rate parameter **(p15** in BRZ, **p24** in reservoir body). Maximum potential consumption rate (prey per predator per day) can be input

1. AS A CONSTANT.

2. AS A LINEAR FUNCTION OF TEMPERATURE.

3. AS A POLYNOMIAL FUNCTION OF TEMPERATURE.

You are prompted for inputs appropriate to your selection. For Option **#1** you are prompted for a rate that is applied to each day. For Option **#2** you are prompted for intercept **(p32)** and slope **(p33)** parameters in the temperature-maximum rate equation

$$RCn_{max}(t) = p32 + p33\ DTp(t). \qquad (23)$$

For Option **#3** you are prompted for 5 slope parameters for a polynomial form of the temperature-maximum rate equation

$$RCn_{max}(t) = p16\ DTp(t)^2 - p17\ DTp(t)^3 + p18\ DTp(t)^4$$
$$- p19\ DTp(t)^5 + p20\ DTp(t)^6 \qquad (14)$$

Response rate parameters may be input

1. AS A CONSTANT

2. AS A LINEAR FUNCTION OF TEMPERATURE

You are prompted for inputs appropriate to your selection. For Option #1 you are prompted for a parameter which is applied to each day. For Option #2 you are prompted for intercept (p34) and slope (p35) parameters in the temperature-response rate equation

$$P14 = p34 + p35 \ DTp(t). \hspace{2cm} (24)$$

You are prompted to input constant intercept parameters for the functional response equations in the BRZ and reseervoir body.

OUTPUT

The Output Options Menu was listed on page 2. Simulation results in the form of tables or graphs may be displayed from this menu. Examples of these outputs follow. You may get a hard copy of any of the summary information and output tables by pressing Shift+PrtXc when the desired information is displayed. You may get a hard copy of a plot by pressing P when the plot is displayed.

Output Option #1
(List Summary of Inputs)

This option lists a short summary of processes, starting numbers, and parameters upon which the current simulation is based. These lists may be printed and attached to simulation results for reference.

```
                         SUMMARY OF INPUTS

  PREDATORS    NUMBER ON DAY ONE [ 85316 ]
               DAILY MORTALITY [ .000135 ]
               % IN BRZ [A LIN FUNC OF TIME W INT .0448 AND SLOPE .000318 ]
             & [A LIN F OF PASS W0 CHANGE OVER PASS RANGE 18962 TO 234621 ]
               BRZ % ACT [A 1 M 1 J .196 J 1 A 1 ]
               RES%ACT[A 1 M 1 J .24 J 1 A 1]

  PREY         PASSAGE [RUN = 2.105479E+07 MPR, DIS W NM 69.7 & RANGE 35.8 ]
               RES TIME [ 13 ]

  TEMPERATURE  [A LIN FUNC OF TIME W INT = 8.74 AND SLOPS .108 ]

  FLOW         [A HORN F OF TIME W MAX = 282 PEAK = 48 SD= 64 ]

  FUNC RESP    MAX CONS PARM [POLYNOMIAL FUNCTION OF TEMP
                   A- .1147 B- .03019 C= .00288 D= .000111 E= 1.476E-06 ]
               BRZ RESP RATE PARM[.0000123 ]
               BRZ THIRD PARM [ 12.4 ]
               RES RESP RATE PARM [ 3.1E-07 ]
               RES THIRD PARM [ 23.5 ]
                         STRIKE ANY KEY TO CONTINUE
```

153

Output Option #2
(List Summary of Results)

```
                        aSUMMARY OF RESULTS


--------------------------------------------------------------------
MONTH TEMP FLOW      PRED      PASSAGE   RES TIME      JUV       Loss    MORT
--------------------------------------------------------------------

   1   10   246     85149     2319001   13         626212     80992  0. 035
   2   14   279     84805     5512965   13        2209855    414680  0.075
   3   17   255     84462     6754356   13        3591880    279714  0.041
   4   20   188     84121     4267188   13        2927644   1236460  0. 290
   5   23   112     83781     1388396   13        1341144    509507  0.367

       17   216     84464    20241910   13        2139347   2521352  0.1246




                   STRIKE ANY KEY TO CONTINUE
```

where

MONTH = April, May, June, July, August.
TEMP = Average water temperature in degrees centigrade during month.
FLOW = Average discharge past McNary Dam in 1000 cubic feet per second during month.
PRED = Average number of predators in reservoir-wide population during month.
PASSAGE = Total number of prey entering reservoir during month.
RES TIME = Average residence time in days of prey in reservoir during month.
JUV = Average density of prey in reservoir body during month.
LOSS = Total number of prey consumed by predators during month.
MORT = Proportion of prey entering reservoir during month that are consumed by predators (LOSS/PASSAGE).

```
                    SUMMARY OF RESULTS - BY AREA

                        BOAT RESTRICTED ZONE
   MONTH   ALL  PRED  BRZ%  ACT%  ACT  PRED   PASSAGE   /PRED   Loss    MORT

     1     85149  0.05  1.00       4234   2319001   0.10    13574  0.0059
     2     84805  0.06  1.00       5026   5512965   0.72   110953  0.0201
     3     84462  0.07  0.20       1139   6754356   1.84    63270  0.0094
     4     84121  0.08  1.00       6591   4267188   1.40   273390  0.0641
     5     83781  0.09  1.00       7363   1388396   0.40    86075  0.0620
           84464  0.07  0.84       4871  20241910   0.89   547262  0.0270


                          RESERVOIR BODY
   MONTH   ALL PRED  RES%  ACT8  ACT PRED   PREY M0   /PRED    LOSS     MORT

     1     85149  0.95  1.00      80915    626212   0.03    67418  0.0291
     2     84805  0.94  1.00      79779   2209855   0.13   303726  0.0551
     3     84462  0.93  0.24      18876   3591880   0.38   216443  0.0320
     4     84121  0.92  1.00      77530   2927644   0.41   963070  0.2257
     5     83781  0.91  1.00      76418   1341144   0.18   423432  0.3050
           84464  0.93  0.85      66704   2139347   0.23  1974089  0.0975

                     STRIKE ANY KEY TO CONTINUE
```

where

MONTH = April, May, June, July, August.
ALL PRED = Average number of predators in reservoir-wide population during month.-
BRZ% = Average proportion of predator population in BRZ during month.
RES% = Average proportion of predator population in reservoir body during month.
ACT% = Average proportion of predators in area that are actively consuming prey during month.
ACT PRED = Average number of predators in area that are actively consuming prey during month.
PASSAGE = Total number of prey entering reservoir during month.
PREY NO = Average density of prey in reservoir body during month.
/PRED = Average daily consumption of prey per predator in area during month.
LOSS = Total number of prey consumed by predators in area in month.
MORT = Proportion of prey entering reservoir during month that are consumed by predators in area (LOSS/PASSAGE).

Area-specific totals for year or yearly averages are listed at the bottom of each column.

```
--------------------------------------------------------------------------
                DAILY ENVIRONMENT & PREDATOR INFORMATION
--------------------------------------------------------------------------

DAY TEMP FLOW     PRED      SURV  BRZ% %ACT BRZ BRZ  NO  % ACT  RES RES  NO

  1   9   215     85316    .9999  0.045  1.000     3849   1.000     81467
  2   9   218     85304    .9999  0.045  1.000     3876   1.000     81429
  3   9   220     85293    .9999  0.046  1.000     3902   1.000     81390
  4   9   223     85281    .9999  0.046  1.000     3929   1.000     81352
  5   9   225     85270    .9999  0.046  1.000     3956   1.000     81314
  6   9   227     85258    .9999  0.047  1.000     3982   1.000     81276
  7   9   230     85247    .9999  0.047  1.000     4009   1.000     81238
  8  10   232     85235    .9999  0.047  1.000     4035   1.000     81200
  9  10   234     85224    .9999  0.048  1.000     4062   1.000     81162
 10  10   236     85212    .9999  0.048  1.000     4088   1.000     81124
 11  10   239     85201    .9999  0.048  1.000     4115   1.000     81086
 12  10   241     85189    .9999  0.049  1.000     4142   1.000     81048
 13  10   243     85178    .9999  0.049  1.000     4168   1.000     81010
 14  10   245     85166    .9999  0.049  1.000     4195   1.000     80972
 15  10   247     85155    .9999  0.050  1.000     4221   1.000     80934

MORE. . .             (Q TO RETURN TO OUTPUT OPTIONS MENU)
```

where

$\quad$ DAY = 1 to 150 corresponding to April through August period of
$\qquad$ salmonid outmigration [t].

$\quad$ TEMP = Temperature in degrees centigrade [DTp(t)].

$\quad$ FLOW = Discharge past McNary Dam in 1000 cubic feet per second
$\qquad$ [DFl(t)].

$\quad$ PRED = Number of predators in reservoir-wide population [Pn(t)].

$\quad$ SURV = Number of predators that survive to following day
$\qquad$ [1 - RDm(t)].

$\quad$ BRZ% = Proportion of reservoir-wide predator population in BRZ
$\qquad$ [RBrz(t)].

$\quad$ %ACT BRZ = Proportion of predators in BRZ that are actively
$\qquad$ consuming prey [RAc1(t)].

$\quad$ BRZ NO = Number of predators in BRZ that are actively consuming
$\qquad$ prey [Pn1(t)].

$\quad$ % ACT RES = Proportion of predators in reservoir body that
$\qquad$ are actively consuming prey [RAc2(t)].

$\quad$ RES NO = Number of predators in reservoir body that are actively
$\qquad$ consuming prey [Pn2(t)].

156

```
--------------------------------------------------------------------------
                    DAILY JUVENILE SALMONID INFORMATION
--------------------------------------------------------------------------

DAY PASS  BRZACT /PRED BRZCON RES LEAVE AVAIL  RESACT /PRED RESCON LOSS MORT

  1 37216  3849 0.05    177 13     0 37E+03 81467 0.02   1369  1547 0.04
  2 39250  3876 0.05    183 13  1901 73E+03 81429 0.02   1384  1567 0.04
  3 41363  3902 0.05    189 13  3809 11E+04 81390 0.02   1401  1590 0.04
  4 43556  3929 0.05    195 13  5726 15E+04 81352 0.02   1422  1617 0.04
  5 45829  3956 0.05    203 13  7656 18E+04`81314 0.02   1446  1649 0.04
  6 48183  3982 0.05    211 13  9603 22E+04 81276 0.02   1474  1686 0.03
  7 50618  4009 0.06    221 13 11570 26E+04 81238 0.02   1506  1727 0.03
  8 53135  4035 0.06    231 13 13560 29E+04 81200 0.02   1543  1774 0.03
  9 55734  4062 0.06    243 13 15575 33E+04 81162 0.02   1584  1826 0.03
 10 58415  4088 0.06    256 13 17618 37E+04 81124 0.02   1629  1885 0.03
 11 61176  4115 0.07    270 13 19693 41E+04 81086 0.02   1680  1951 0.03
 12 64018  4142 0.07    286 13 21800 45E+04 81048 0.02   1737  2023 0.03
 13 66940  4168 0.07    304 13 23943 49E+04 81010 0.02   1799  a103 0.03
 14 69941  4195 0.08    324 13 26123 53E+04 80972 0.02   1867  2191 0.03
 15 73019  4221 0.08    346 13 28342 58E+04 80934 0.02   1942  2288 0.03

MORE...                (Q TO RETURN TO OUTPUT OPTIONS MENU)
```

where

DAY = 1 to 150 corresponding to April through August period of salmonid outmigration (t) .

PASS = Number of prey passing McNary Dam [DJv (t)].

BRZACT = Number of predators in BRZ that are actively consuming prey [ARn1(t)].

/PRED = Daily consumption of prey per predator in BRZ [RCn1(t)].

BRZCON = Loss of prey to predators in BRZ on day [SC1(t)].

RES = Residence time of prey in reservoir in days [RTm(t)].

LEAVE = Number of prey leaving reservoir on day [Jv(t) /RTmE (t)] .

AVAIL = Number of prey in reservoir body during day [Jv2 (t)].

RESACT = Number of predators in reservoir body that are actively consuming prey [APn2 (t)] .

/PRED = Daily consumption of prey per predator in reservoir body [RCn2(t)].

RESCON = Loss of prey to predators in reservoir body on day [SC2(t)].

LOSS = Total loss of prey to predators on day [SC1(t) + SC2(t)].

Output Option #6
(Plot Selected Variables)

You **may** plot daily results versus day or daily results versus each other. When you choose this option, a list of variables that can be plotted are displayed and you are prompted to select a variable for the y and x axes. X-axis variables are automatically sorted from minimum to maximum. Plotable variables correspond with those listed in Output Options 4 and 5. The plot is automatically scaled so that the plot fills the Y-axis. You may print graphs by pressing P after the plot is drawn on the screen. (This option was programmed for an IBM graphics printer and may not work on other printers.) Example inputs and the resulting graph are shown.

```
                        PLOT SELECTED VARIABLES

THE FLOOWING VARIABLES MAY BE PLOTTED

        DAY         TEMP        FLOW        PASSIN      PREY        PASSOUT
        PRED        BRZ%        %ACTBRZ     %ACTRES     BRZAPRED    RESPARED
        RECONSBRZ   RCONSRES    LOSSBRZ     LOSSRES     Loss        MORT

SELECT Y-AZIS VARIABLE BY ENTERING ITS NAME [LOSS]: ?

SELECT X-AXIS VARIABLE BY ENTERING ITS NAME [DAY]: ?

INDICATI MONITOR TYPE (=IBM, 2=MOD D) [1] ?
```


LOSS (X 1000) versus DAY (X 1000)
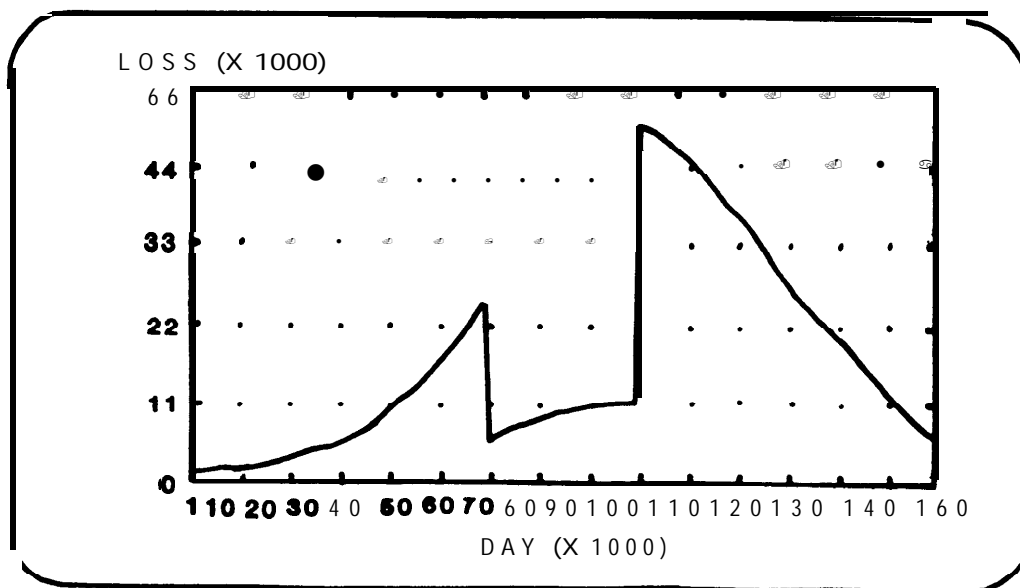
COPIES

A copy of RESPRED may be obtained by sending a diskette and self-addressed mailer with stamp to the author. RESPRED includes the following files

1. RESPRED1.EXE: the executable program file.

2. RESPRED1,KEY: file containing default data set.

3. RESPRED1.BAS: file containing the source code.

4. RESPRED1.DOC: file containing user's guide.

REFERENCES

Beamesderfer, R.C., B.E. Rieman, and S. Vigg. 1988. Simulation of predation by resident fish on juvenile salmonids in a Columbia River reservoir. In T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonid in John Day Reservoir, 1983-86. Final report (Contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) to Bonneville Power Administration, Portland, Oregon.

Ebel, W.J. 1977. Major passage problems. Pages 33-39 *in* E. Schwiebert, editor. Columbia River salmon and steelhead. American Fisheries Society Special Publication 10, Washington D.C.

Rieman, B.E., R.C. Beamesderfer, and S. Vigg. 1988. Predation by resident fish on juvenile salmonids in a mainstem Columbia River reservoir: Part IV. Total loss and mortality of juvenile salmonids to northern squawfishwalleye, and smallmouth bass. In T.P. Poe and B.E. Rieman, editors. Predation by resident **fish on juvenile salmonids in John** Day **Reservoir 1983-86.** Final report (Contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) to Bonneville Power Administration, Portland, Oregon.

Data Set Documentation

JOHN C. ELLIOTT

Oregon Department of Fish and Wildlife
17330 SE Evelyn Street, Clackamas, Oregon **97015**, USA

Data collected during routine sampling, during an angler survey, from analyses of fish scales, and from radiotagged fish are stored on magnetic tapes. The sections of this attachment are the contents of the first file on each of the tapes and contain information on the kind of data, what it was used for, how to retrieve the data sets, the location of variables and descriptions of variables and variable codes. A hardcopy of these files are attached to each respective tape.

Copies of these tapes are archived with:

The Bonneville Power Administration, Portland, Oregon
ODFW Data Processing Section, Portland, Oregon
ODFW Research and Development Section, Clackamas, Oregon

ODFW personnel familiar with data storage and coding include:

Anthony Nigro   657-2038
John Elliott   657-2035
Raymond Beamesderfer   657-2036

EFFORT, CATCH AND FISH BIOLOGICAL DATA

This documentation is the first of five files on this tape, an information file. This tape contains yearly effort, catch and individual fish biological information (Files 2-5) collected by the Oregon Department of Fish and Wildlife (0DFW) in the John Day Pool of the Columbia River from 1983 to 1986. The purpose of the study was to describe the abundance and distribution of major predators of juvenile salmonids. An associated study to determine consumption rates and prey selection of major predators during the same time was conducted by the U.S. Fish and Wildlife Service (usfws). Portions of the data collected by USFWS are included in these files. Both studies were funded by the Bonneville Power Administration (BPA) and have worked together to describe the extent of predation in this area. Annual and final reports of these studies are availible from BPA.

Files 2-5 contain only data. All files are written in ASCII, Record Format = fixed block, Logical Record Length = 80, Blocksize = 9040 and Density = 1600 bites per inch. Programs to write disk files from the BPA mainframe computer OS data sets to this tape using the ROSCOE environment in use during 1988 are:

```
//PJI814T JOB ('PJI ,NJ9 , ,F11PM ,PF200'),'RAYB 657-2036',
//         CLASS=S,PRTY=4,
//         MSGCLASS=E
//*ROUTE    PRINT RSCS41
//*
//*
//S1       EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1   DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.TAPE1,
//         DISP=SHR
//SYSUT2   DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.TAPE1,
//         UNIT=TAPE,
//         LABEL=(1,NL,,,EXPDT=98000),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//         VOL=(,RETAIN,,,SER=X91292),
//         DISP=NEW
//SYSIN    DD DUMMY
//*
//S2       EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1   DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.CRPP3,
//         DISP=SHR
//SYSUT2   DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.CRPP3,
//         UNIT=TAPE,
//         LABEL=(2,NL,,,EXPDT=98000),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//         VOL=SER=X91292,
//         DISP=NEW
//SYSIN    DD DUMMY
//*
//S3       EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1   DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.CRPP4,
//         DISP=SHR
//SYSUT2   DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.CRPP4,
//         UNIT=TAPE,
//         LABEL=(3,NL,,,EXPDT=98000),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//         VOL=SER=X91292,
//         DISP=NEW
//SYSIN    DD DUMMY
//*
//S4       EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1   DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.CRPP5,
//         DISP=SHR
//SYSUT2   DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.CRPP5,
//         UNIT=TAPE,
//         LABEL=(4,NL,,,EXPDT=98000),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//         VOL=SER=X90977,
//         DISP=NEW
//SYSIN    DD DUMMY
//*
//S5       EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1   DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.CRPP6,
//         DISP=SHR
//SYSUT2   DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.CRPP6,
//         UNIT=TAPE,
//         LABEL=(5,NL,,,EXPDT=98000),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//         VOL=SER=X90977,
//         DISP=NEW
//SYSIN    DD DUMMY
//*
```

Variable List

VARIABLE	NUMBER OF CHARACTERS	ALPHA OR NUMERIC	COLUMNS	JUSTIFICATION
DATE	6	N	1- 6	R
LOCATION	5	N	7-11	R
GEAR	2	N	12-13	R
START TIME	4	N	14-17	R
STOP TIME	4	N	18-21	R
EFFORT	4	N	22-25	R
DEPTH (MIN)	2	N	26-27	R
DEPTH (MAX)	3	N	28-30	R
TEMPERATURE	2	N	31-32	R
SECCHI	2	N	33-34	R
WAVE HEIGHT	1	N	35	
FISH NUMBER	2	N	36-37	R
SPECIES	3	A	38-40	R
COLLECTION NO.	3	N	41-43	R
SCALE NO.	4	N	44-47	R
FORK LENGTH	3	N	48-50	R
WEIGHT	4	N	51-54	R
SEX	1	A	55	
MATURITY STAGE	1	N	56	
DISPOSITION	2	N	57-58	R
TAG COLOR	2	A	59-60	R
TAG NUMBER	5	N	61-65	R
SECONDARY MARK	1	N	66	
AGE STRUCTURE	1	N	67	
DOCUMENT NO.	4	N	68-71	R

Date: Date of sample. (format Day, Month, Year)

Location: Place sampling gear was deployed.
          (Six digit code)
  Section - is the largest unit and is designated by the first two
            numbers in the six digit location code.
    14 - Upper The Dalles Dam Pool (River mile 207 - 216)
    15 - Lower John Day Dam Pool (River mile 216 - 279)
    16 - Upper John Day Dam Pool (River mile 279 - 292)
    17 - Lower McNary Dam Pool (River mile 292 - 324)
  Transect - there are several transects within a section. They are
            designated by the first three numbers in the six
            digit location code. Our transects include:
    159 - John Day Forebay
    156 - Arlington
    151,163 - Irrigon/Patterson
    161 - McNary Tailrace
  Station - there are several stations within a transect and they are
            designated by the fourth and fifth numbers in the six
            digit code.
  Site - is the smallest unit and is designated by using the sixth
          number in the six digit location code. There may or may
          not be sites within a station. Site codes are used to
          identify a very specific location generally used for fixed
          sampling gears and/or angling locations around dams.

Transect, Station	Site
159	John Day forebay
01	John Day powerhouse (OR shore to unit 20, upstream 200 yards)
	011 OR shore to adult fish ladder
	012 adult fish ladder to unit 1
	013 units 1-5
	014 units 6-20
02	John Day spillway (upstream 200 yards)
	021 spill gates 11-20
	022 spill gate 10 to navigation lock
03	Navigation lock channel
04	WA corner (nav. lock channel to WA shore then upstream to culvert entrance to backwater)
	041 cement foundation north of corps moorage
	042 WA shore midway between rock signs
	043 E rock sign
	044 FWS prey site
	045 FWS prey site

```
                    046 corner
                    047 point outside culvert
        05      WA backwater
        06      WA shore (entrance of backwater to red flag 4)
        07      Open water (200 yards above dam to red flag 4)
        08      OR shore (200 yds. above dam to 100 yds below
                John Day river mouth)
                    081 submerged, rocky point just inside deadline
                    082 OR shore between dam and restricted boundary
        09      John Day River (100 yds. below mouth to red flag
                4 and upstream 2.5 miles)
                    091 100 yards below mouth to railroad bridge
                    092 railroad bridge to red flag 4
                    093 railroad bridge to I-84 bridge
                    094 east shore (I-84 bridge upstream 2.5 miles)
                    095 west shore (I-84 bridge upstream 2.5 miles)
                    096 west shore off point at first west bend
                    (also in 095)
        10      John Day River (more than 2.5 miles upriver)

156         Arlington

        01      Arlington marina
        02      OR shore (marina to end of transect)
                    021 point west of Jones Canyon
        03      Jones Canyon backwater
        04      WA shore (railroad light to pump intake)
                    041 irrigation pump intake
        05      Boat ramp inlet
                    051 point west of boat ramp
                    052 beach in NE corner
        06      Ferry landing
        07      Open water (lower transect)
        08      WA shore (piles to Roosevelt)
        09      Roosevelt inlet
                    091 inlet at east end of station
        10      WA elevator
        11      Offshore shelf
        12      Open water (between grain elevators)
        13      OR shore (marina to railroad light)
        14      WA shore (sand to willow bush)
        15      WA shore (willow bush to rounded knoll)
        16      Open water (sand to rounded knoll)
        17      OR shore (railroad light to apron)
        18      WA shore (rounded knoll to green flag 24)
        13      Open water (upper transect end)
        20      OR shore (apron to end of transect)
                    201 beach at east end of station

163         Irrigon

        01      WA shore (flag 64 to shallows off red buoy 62)
                    011 point where shallows drop off to deep water near
                    shore (osprey tree)
```

02   Open water (flag 64 to flag 62)
03   OR shore (flag 64 to flag 62)
            031 channel side of shelf (flag 62 to flag 64)
            032 shallows in mid-river (south of site 1)
            033 deep water and OR shore (south of site 2)
04   WA shore (flag 59 to flag 62)
            041 shallows at east end of station
05   Open water (flag 59 to flag 62)
06   OR shore (flag 59 to flag 62)
            061 Irrigon Marina
07   WA shore (flag 57 to flag 59)
08   Open water (flag 57 to flag 59)
09   OR shore (flag 57 to flag 59)
10   South side Paterson Island (point to flag 57)
            101 directly across from refuge boat ramp
11   Open water (from line dissection Paterson Island point
        and grain elevator to flag 57)
12   OR shore (grain elevator to flag 57)

151   Paterson

01   Paterson Slough (WA rocky shoreline)
            011 shoreline (boat ramp to "line-up" point)
            012 WA shoreline along railroad tracks
02   Paterson Slough (backwater shallows)
03   Paterson Slough (inside island to trestle opening)
            031 east from trestle opening to island point
            032 deep hole inside trestle
            033 mid-channel inside trestle opening
04   Channel side of Paterson trestle (boat ramp to island
        point)
            041 east from trestle opening to island point
            042 west from trestle opening to boat ramp
            043 offshore outside trestle opening
05   Open water (Flag 55 to grain elevator)
06   OR shore (Flag 55 upper tip of upper Blalock Island)
07   WA shore and shallow water (lower end of transect to
        Paterson boat ramp)
08   Open water (north channel-lower end of transect to
        flag 55)
09   Open water (E. tip of upper Blalock Island to flag 55)
            091 shallow water adjacent to flag 55
            092 shallow water adjacent to flag 53
            093 combination of 091 and 092

161   McNary Tailrace

01   Powerhouse (to end of boat restricted zone)
            011 units 1-7
            012 units 8-14
            013 OR shore (riffle to end of boat restricted zone
02   Spillway (downstream to end of navigation lock)
        (end of boat restricted zone)
            021 adult fish ladder pool

022 attraction water and sluiceway spill
         023 gates 21-22
         024 gates 11-20
         025 gates 1-10
         026 south side of navigation lock
03   Navigation lock to power line point RM 291.1
         031 navigation lock channel
04   Open water (end of navigation lock to power line point)
05   OR shore--PH point (rm 292) to marina light
         053 concrete pillars at pond creek mouth
         055 shallows between 053 and power lines
         059 gravel bar (bridge to marina light)
06   East Plymouth Slough (power line point to end of slough)
         061 power line point to bridge
         062 WA shore (bridge to tip of island)
         063 WA shore (tip of island to swim buoys)
         064 end of slough to swim buoys
         065 island shore (swim buoys to upstream tip of island
         066 upstream from island tip (from bar toward WA
             shore)
07   South shore of Plymouth Island
         071 marina inlet
         072 from marina to eastern tip of island
         073 from marina to western tip of island
08   Open water (power line to Umatilla River mouth
         and Plymouth Is. light)
09   OR shore (marina light to Umatilla River mouth)
         091 marina
         092 swim area
         093 pump house west of swim area
         094 inlet eddy 500 yds. west of pump house
10   West Plymouth Slough (starts at downstream tip of
         island)
         101 WA shore (west end to trap-net point, includes
         bunker)
         102 WA shore (trap-net point to end of slough)
         103 Island shore (end of slough to across from
         trap-net point)
         104 Island shore (across from trap-net point to
         tip of island)
         105 mid channel (trap-net point to tip of island)
         106 submerged island at east end
11   WA shore (west Plymouth to end of transect)
         111 stumps off tip of Plymouth Island
         112 trap-net trees on WA shore across from stumps
12   Open water (Plymouth Island light-Umatilla River
         mouth to end of transect)
13   Umatilla River and mouth
         131 outside of bridges
         132 inside of bridges
14   OR shore (Umatilla River mouth to pump house)

Gear: Type of gear deployed

01   Bottom gill net (6 ft. x 120 ft.) – fixed
02   Bottom gill net (8 ft. x 150 ft.) – fixed
03   Surface gill net (6 ft. x 120 ft.) – fixed
04   Surface gill net (8 ft. x 150 ft.) – fixed
05   Surface gill net (6 ft. x 120 ft.) – drift
06   Surface gill net (8 ft. x 150 ft.) – drift
07   Bottom gill net (8 ft. x 120 ft.) – old beater
08   CRM surface gill net (20 ft. x 200 ft.) – 4 inch stretch
        mesh – drift
09   CRM surface gill net (20 ft. x 200 ft.) – 4 inch stretch
        mesh – fixed
10   Surface gill net (8 ft. x 60 ft.) – drift
11   USFWS bottom gill net (6 ft. x 200 ft) – 5 inch stretch mesh
12   USFWS bottom gill net (6 ft. x 200 ft) – 6 inch stretch mesh
13   USFWS bottom gill net (6 ft. x 200 ft.) – 1, 2, 3, 4, 5, 6,
        7, 8 cm stretch mesh – experimental
14   Bottom gill net (8 ft. x 120 ft) – 4, 4.5, 5, 4, 4.5, 5-inch
        stretch mesh
15   Vertical gill net (100 ft. x 10 ft.) – 2.5 inch stretch mesh
16   Vertical gill net (100 ft. x 10 ft.) – 3.5 inch stretch mesh
17   Vertical gill net (100 ft. x 10 ft.) – 4.0 inch stretch mesh
18-19   Other gill nets
20   Trap net (Fall River hatchery)
21   Trap net (USFWS)
22   Trap net (modified Lake Erie – 10 ft.)
23   Trap net (modified Lake Erie – 15 ft.)
24   Trap net (fish gilled in mesh – 10 ft.)
25   Trap net (fish gilled in mesh – 15 ft.)
26-29   Other trap nets
30   Beach seine (USFWS prey seine) 8 ft. x 100 ft. – .25
        inch mesh
31   Beach seine (CRM – 15 ft. x 200 ft. 3 inch mesh)- floating
32   Beach seine (CRM – 10 ft. x 400 ft. 3 inch mesh)- floating
33-34   Other beach seines
35   Minnow trap
36-39   Prey gill nets (USFWS)
40   Angler – creeled
41   Angler – mailed in tag return
42   Angler – tag box tag return
43   Angler - personally returned tag (non-random)
45   **Angler - other or unknown source of tag return**
46-49   Other angler types
50   Bottom trawl (USFWS) - small
51   Mid-water trawls (USFWS)
52   Bottom trawl (USFWS) - large
53-59   Other trawls
60   Electroshocker (starboard boom, Woolridge sled)
61   Electroshocker (USFWS, Smith-Root boat)
62   Electroshocker (bow platform, Woolridge sled)-ODFW
63-69   Other electroshockers
70   Angling (lure from dam)
71   Angling (smolt from dam)

72	Angling (worm from dam)
73	Angling (bait and lure from dam)
74	Angling (lure from boat)
75	Angling (smolt from boat)
76	Angling (worm from boat)
77	Angling (bait and lure from boat)
78	Angling (lure from shore)
79	Angling (smolt from shore)
80	Angling (worm from shore)
81	Angling (bait and lure from shore)
82	Angling (Ammocoete from dam)
83-88	Other angling
89	Angling (lure and smolt from dam: inseparable data)
90	Black cod trap (unbaited)
91	Black cod trap (baited)
92-95	USFWS undesignated
99	All USFWS gear combined

Start time: Time gear was deployed (Military)

Stop Time: Time gear was retrieved (Military)

Effort: The time in hundreths of hours that gear was sampling.

Depth of set (MIN): Depth of bottom at shallowest part of set (feet)

Depth of set (MAX): Depth of bottom at deepest part of set (feet)

Temperature: Surface water temperature (Degrees C)

Secchi: Secchi depth reading (Meters and tenths of meters)

Wave Height: Vertical distance from crest to trough
    1 = 0-6"
    2 = 6-18"
    3 = 18-36"
    4 = 36"+

Fish number: Number of each individual fish in a set

Species:
    WAL = walleye
    SQF = squawfish
    SMB = smallmouth bass
    CHC = channel cats
    STG = white sturgeon

Collection number: For use with USFWS sampling

Scale number: Unique number identifying scale sample

Fork length: Measurement to fork of caudal fin (in mm)

Weight: Measurement to nearest 10 grams

Sex:
    M = male
    F   female
    0 = unknown

Maturity:
    0 = not determined
    1 = Immature - gonads are thin or threadlike: females
        show a greater degree of veination than males.
    2 = Developing - sex is easily determined from gonads
        (males are white, females are yellowish tinged
        with red), but eggs or milt do not flow freely
        with gently pressure.
    3 = Ripe - eggs or milt flow freely with gentle
        pressure.
    4 = Spent - sex is easily determined but gonads are
        flaccid and may show striations: some eggs or
        sperm may still be present.

Fish disposition: The condition of an individual fish at capture and
                    its subsequent disposal, and the tagging status of
                    the fish at capture.

    Condition at capture and subsequent disposal:
    0 = Unknown, no information
    1 = Alive at capture and subsequently tagged and released.
    2 = Alive at capture and subsequently released untagged because
        it was undersized (WAL, SQF & CHC < 250 mm, SMB < 200mm).
    3 = Alive at capture and subsequently sacrificed.
    4 = Alive at capture and subsequently released without a
        new tag (WAL, SQF, & CHC > 250 mm, SMB > 200mm).
    5 = Dead at capture or "morted" due to condition and undersized.
    6 = Dead at capture or "morted" due to condition and taggable size.
    7 = Captured by one agency and given to the other for
        processing. For tagging and stomach content data only.
    8 = Excess fish released without processing by USFWS.

    Tagging status at capture:
    0 = Unknown, no information.
    1 = Never before tagged.
    2 = 1982 tag present (T-anchor tag with left opercle punched).
    3 = 1983 tag present (Spaghetti tag with left opercle punched).
    4 = 1984 tag present (Spaghetti tag with left ventral clipped).
    5 = 1985 tag present (Thin spaghetti tag with RV clipped).
    6 = 1986 tag present (Thin spaghetti tag with LV clipped).
    7 = Another tag present (not predator-prey mark)

    A = Indistinguishable 1982-83 tag loss
    B = 1982 tag loss (LOP and/or T-anchor tag scar)
    C = 1983 tag loss (LOP and Spaghetti tag scar)
    D = 1984 tag loss (LV and Spaghetti tag scar)

E = 1985 tag loss (**RV** and Spaghetti tag scar)
F = 1986 tag loss (**LV** and Spaghetti tag scar)

Tag color: Color of spagetti or dart T-tag
   Column 58 is the tag color
   B = blue
   G = green
   O = orange
   R = brown
   W = white
   Y = yellow
   Column 59 is tag style
   1 **=** T-tag
   2 **=** spaghetti

Tag number: Number printed on tag (unique when combined with tag color)

Year	Tag Color	Tag Number
1982	B1	0001-2000, 2201-2300
	G1	0001-0900, 1201-1300, 2001-2100, 2401-2500
	R1	0001-0201
	W1	0001-0021, 1501-1534, 12955-13100, 14001-14900
	Y1	0001-0400
1983	02	12257-14500
	R1	00100-00200
	W1	01701-01800
	Y2	50001-54406
1984	B2	40001-49999
	02	16001-17463, 18001-18466
	Y2	51533-51566; 51577-51585, 51601-51605, 58400-53421, 54507-54600, 55001-56000
1985	02	13756-13800, 14001-14041, 14301-14388, 14601-14644, 2000-21999
	Y2	53423-53472, 53501-53504, 53901-53983 54601-54654, 54697-54732, 54801-54818
1986	02	22001-24599
	Y2	59501-61500

Secondary mark: The mark made in addition to a tag.
    0 =no mark
    1 = left opercle punch
    2 = right opercle punch
    3 = left pelvic fin clip
    4 = right pelvic fin clip

Age: Which aging structure(s) were taken for age analysis.
    0 = none
    1 = scales
    2 = scales and opercle
    3 = pectoral fin ray

Document number: Number assigned to each sample.

Period: A variable used to separate time intervals primarily for
          abundance estimates.

	1982	1983	1984	1985	1986
01	1/01-1/16	1/01-1/15	1/01-1/14	1/01-1/12	1/01-1/11
02	1/17-1/30	1/16-1/29	1/15-1/28	1/13-1/26	1/12-1/25
03	1/31-2/13	1/30-2/12	1/29-2/11	1/27-2/09	1/26-2/08
04	2/14-2/27	2/13-2/26	2/12-2/25	2/10-2/23	2/09-2/22
05	2/28-3/13	2/27-3/12	2/26-3/10	2/24-3/09	2/23-3/08
06	3/14-3/27	3/13-3/26	3/11-3/24	3/10-3/23	3/09-3/22
07	3/28-4/10	3/27-4/09	3/25-4/07	3/24-4/06	3/23-4/05
08	4/11-4/24	4/10-4/23	4/08-4/21	4/07-4/20	4/06-4/19
09	4/25-5/08	4/24-5/07	4/22-5/05	4/21-5/04	4/20-5/03
10	5/09-5/22	5/08-5/21	5/06-5/19	5/05-5/18	5/04-5/17
11	5/23-6/05	5/22-6/04	5/20-6/02	5/19-6/01	5/18-5/31
12	6/06-6/19	6/05-6/18	6/03-6/16	6/02-6/15	6/01-6/14
13	6/20-7/03	6/19-7/02	6/17-6/30	6/16-6/29	6/15-6/28
14	7/04-7/17	7/03-7/16	7/01-7/14	6/30-7/20*	6/29-7/12
15	7/18-7/31	7/17-7/30	7/15-8/04*	7/21-8/03	7/13-7/26
16	8/01-8/14	7/31-8/13	8/05-8/18	8/04-8/17	7/27-8/09
17	8/15-8/28	8/14-8/27	8/19-9/01	8/18-8/31	8/10-8/23
18	8/29-9/11	8/28-9/10	9/02-9/15	9/01-9/14	8/24-9/06
19	9/12-9/25	9/11-9/24	9/16-9/29	9/15-9/28	9/07-9/20
20	9/26-10/9	9/25-10/8	9/30-10/13	9/29-10/12	9/21-10/04
21	10/10-10/23	10/09-10/22	10/14-10/27	10/13-10/26	10/05-10/18
22	10/24-11/06	10/23-11/05	10/28-11/10	10/27-10/09	10/19-11/01
23	11/07-11/20	11/06-11/19	11/11-11/24	11/10-11/23	11/02-11/15
24	11/21-12/04	11/20-12/03	11/25-12/08	11/24-11/07	11/16-11/29
25	12/05-12/18	12/04-12/17	12/09-12/22	12/08-12/21	11/30-12/13
26	12/19-12/31	12/18-12/31	12/23-12/31	12/22-12/31	12/14-12/31

* (includes one week of break)

ANGLER SURVEY DATA

This documentation is the first of nine files on this tape. This tape contains yearly angler survey pressure counts (Files **2-5)** and interview information (Files **6-9)** collected by the Oregon Department of Fish and Wildlife **(ODFW)** in the John Day Pool of the Columbia River from 1983 to 1986. This data was collected as a part of the study to describe the abundance and distribution of major predators of juvenile salmonids. The information was needed to estimate the number of removals of tagged and untagged target fish by anglers in the study area to reduce bias on abundance estimates. In the process, a great deal of demographic information was collected and is contained in the data sets (Files 6-9) on this tape. This study was funded by the Bonneville Power Administration **(BPA).** Annual and final reports of these studies are availible from BPA.

Files 2-9 contain only data. Files l-8 are written in ASCII, Record Format **=** fixed block, Logical Record Length **=** 80, Blocksize = 9040 and Density = 1600 bites per inch. File 9 has the same parameters as files l-8 except Logical Record Length = 133 and Blocksize =9044 Programs to write disk files from the BPA mainframe computer OS data sets to this tape using the ROSCOE environment in use during 1988 are:

```
//PJI814T JOB ('PJI ,NJ9 , ,F11PM ,PF200'),'RAYB 657-2036',
//         CLASS=S,PRTY=4,
//         MSGCLASS=E
//*ROUTE    PRINT RSCS41
//*
//*
//S1       EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1   DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.TAPE2,
//         DISP=SHR
//SYSUT2   DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.TAPE2,
//         UNIT=TAPE,
//         LABEL=(1,NL,,,EXPDT=98000),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//         VOL=(,RETAIN,,,SER=X90977),
//         DISP=NEW
//SYSIN    DD DUMMY
//*
//S2       EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1   DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.ANGCNT3,
//         DISP=SHR
//SYSUT2   DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.ANGCNT3,
//         UNIT=TAPE,
//         LABEL=(2,NL,,,EXPDT=98000),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//         VOL=SER=X90977,
//         DISP=NEW
//SYSIN    DD DUMMY
//*
//S3       EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1   DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.ANGCNT4,
//         DISP=SHR
//SYSUT2   DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.ANGCNT4,
//         UNIT=TAPE,
//         LABEL=(3,NL,,,EXPDT=98000),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//         VOL=SER=X90977,
//         DISP=NEW
//SYSIN    DD DUMMY
//*
//S4       EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1   DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.ANGCNT5,
//         DISP=SHR
//SYSUT2   DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.ANGCNT5,
//         UNIT=TAPE,
//         LABEL=(4,NL,,,EXPDT=98000),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//         VOL=SER=X90977,
//         DISP=NEW
//SYSIN    DD DUMMY
//*
```

```
//S5       EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1    DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.ANGCNT6,
//             DISP=SHR
//SYSUT2    DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.ANGCNT6,
//             UNIT=TAPE,
//             LABEL=(5,NL,,,EXPDT=98000),
//             DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//             VOL=SER=X91293,
//             DISP=NEW
//SYSIN     DD DUMMY
//*
//S6       EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1    DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.ANGINT3,
//             DISP=SHR
//SYSUT2    DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.ANGINT3,
//             UNIT=TAPE,
//             LABEL=(6,NL,,,EXPDT=98000),
//             DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//             VOL=SER=X90977,
//             DISP=NEW
//SYSIN     DD DUMMY
//*
//S7       EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1    DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.ANGINT4,
//             DISP=SHR
//SYSUT2    DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.ANGINT4,
//             UNIT=TAPE,
//             LABEL=(7,NL,,,EXPDT=98000),
//             DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//             VOL=SER=X90977,
//             DISP=NEW
//SYSIN     DD DUMMY
//*
//S8       EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1    DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.ANGINT5,
//             DISP=SHR
//SYSUT2    DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.ANGINT5,
//             UNIT=TAPE,
//             LABEL=(8,NL,,,EXPDT=98000),
//             DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//             VOL=SER=X90977,
//             DISP=NEW
//SYSIN     DD DUMMY
//*
//S9       EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1    DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.ANGINT6,
//             DISP=SHR
//SYSUT2    DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.ANGINT6,
//             UNIT=TAPE,
//             LABEL=(9,NL,,,EXPDT=98000),
//             DCB=(RECFM=FB,LRECL=133,BLKSIZE=9044,OPTCD=Q,DEN=3),
//             VOL=SER=X90977,
//             DISP=NEW
//SYSIN     DD DUMMY
```

Angler Count Variable List

VARIABLE	NUMBER OF CHARACTERS	ALPHA OR NUMERIC	COLUMNS	JUSTIFICATION
LOCATION	2	N	1-2	R
DATE	6	N	3-8	R
PERIOD	2	N	9-10	R
DAY TYPE	2	N	11-12	R
ZERO FILL	10	N	13-22	R
START TIME	4	N	23-26	R
STURGEON BOATS	2	N	27-28	R
STG BOAT ANGLERS	3	N	29-31	R
OTHER BOATS	2	N	32-33	R
OTH BOAT ANGLERS	3	N	34-36	R
TOTAL BOATS	2	N	37-38	R
STG BANK ANGLERS-OR	2	N	39-40	R
STG BANK ANGLERS-WA	2	N	41-42	R
STG BANK TOTAL	2	N	43-44	R
SHAD BANK ANGLERS-OR	2	N	45-46	R
SHAD BANK ANGLERS-WA	2	N	47-48	R
SHAD BANK TOTAL	3	N	49-51	R
OTH BANK ANGLERS-OR	1	N	52-53	R
OTH BANK ANGLERS-WA	1	N	54-55	R
OTH BANK TOTAL	2	N	56-57	R
DOCUMENT NO.	4	N	58-61	R

Angler Count Variable Descriptions and Data Codes

Location: Place sampled
    10 = Umatilla, OR Shore
    24 = Umatilla, WA Shore
    30 = John Day River Trailer Counts
    31 = John Day River Direct Counts

Date: Date of sample. (format Day, Month, Year)

Period: A variable used to separate time intervals

	1982	1983	1984	1985	1986
01	1/01-1/16	1/01-1/15	1/01-1/14	1/01-1/12	1/01-1/11
02	1/17-1/30	1/16-1/29	1/15-1/28	1/13-1/26	1/12-1/25
03	1/31-2/13	1/30-2/12	1/29-2/11	1/27-2/09	1/26-2/08
04	2/14-2/27	2/13-2/26	2/12-2/25	2/10-2/23	2/09-2/22
05	2/28-3/13	2/27-3/12	2/26-3/10	2/24-3/09	2/23-3/08
06	3/14-3/27	3/13-3/26	3/11-3/24	3/10-3/23	3/09-3/22
07	3/28-4/10	3/27-4/09	3/25-4/07	3/24-4/06	3/23-4/05
08	4/11-4/24	4/10-4/23	4/08-4/21	4/07-4/20	4/06-4/19
09	4/25-5/08	4/24-5/07	4/22-5/05	4/21-5/04	4/20-5/03
10	5/09-5/22	5/08-5/21	5/06-5/19	5/05-5/18	5/04-5/17
11	5/23-6/05	5/22-6/04	5/20-6/02	5/19-6/01	5/18-5/31
12	6/06-6/19	6/05-6/18	6/03-6/16	6/02-6/15	6/01-6/14
13	6/20-7/03	6/19-7/02	6/17-6/30	6/16-6/29	6/15-6/28
14	7/04-7/17	7/03-7/16	7/01-7/14	6/30-7/20*	6/29-7/12
15	7/18-7/31	7/17-7/30	7/15-8/04*	7/21-8/03	7/13-7/26
16	8/01-8/14	7/31-8/13	8/05-8/18	8/04-8/17	7/27-8/09
17	8/15-8/28	8/14-8/27	8/19-9/01	8/18-8/31	8/10-8/23
18	8/29-9/11	8/28-9/10	9/02-9/15	9/01-9/14	8/24-9/06
19	9/12-9/25	9/11-9/24	9/16-9/29	9/15-9/28	9/07-9/20
20	9/26-10/9	9/25-10/8	9/30-10/13	9/29-10/12	9/21-10/04
21	10/10-10/23	10/09-10/22	10/14-10/27	10/13-10/26	10/05-10/18
22	10/24-11/06	10/23-11/05	10/28-11/10	10/27-10/09	10/19-11/01
23	11/07-11/20	11/06-11/19	11/11-11/24	11/10-11/23	11/02-11/15
24	11/21-12/04	11/20-12/03	11/25-12/08	11/24-11/07	11/16-11/29
25	12/05-12/18	12/04-12/17	12/09-12/22	12/08-12/21	11/30-12/13
26	12/19-12/31	12/18-12/31	12/23-12/31	12/22-12/31	12/14-12/31

* (includes one week of break)

Day Type:
    10 = Weekday
    01 = Weekend

Zero Fill: No data in these spaces

Start time: Time count was begun (Military)

Sturgeon boats: Number of boats fishing for white sturgeon

Sturgeon boat anglers: Number of anglers in the boats observed
                       fishing for white sturgeon

Other boats: Number of boats other than fishing for white sturgeon

Other boat anglers: Number of anglers in the boats observed fishing
                    for species other than white sturgeon

Total boats: Sum of white sturgeon boats and other boats

Sturgeon bank anglers (OR): Number of anglers on the Oregon shore
                            observed fishing for white sturgeon

Sturgeon bank anglers (WA): Number of anglers on the Washington shore
                            observed fishing for white sturgeon

Sturgeon bank anglers (Total): Sum of Oregon and Washington white
                               sturgeon bank anglers

Shad bank anglers (OR): Number of anglers on the Oregon shore
                        observed fishing for shad

Shad bank anglers (WA): Number of anglers on the Washington shore
                        observed fishing for shad

Shad bank anglers (Total): Sum of Oregon and Washington shad
                           bank anglers

Other bank anglers (OR): Number of anglers on the Oregon shore
                         observed fishing for other species

**Other bank anglers (R): Number of anglers on the Washington shore
                          observed fishing for other species**

Other bank anglers (Total): Sum of Oregon and Washington other
                            species bank anglers

Document number: Number assigned to each sample.

Angler Interview Variable List

VARIABLE	NUMBER OF CHARACTERS	ALPHA OR NUMERIC	COLUMNS	JUSTIFICATION
LOCATION	2	N	1-2	R
DATE	6	N	3-8	R
PERIOD	2	N	9-10	R
DAY TYPE	2	N	11-12	R
INTERVIEW TIME	4	N	13-16	R
ANGLER TYPE	1	N	17	R
SPECIES SOUGHT	1	N	18	R
TRIP CODE	1	N	19	R
NUMBER OF ANGLERS	2	N	20-21	R
NUMBER MALE	1	N	22	R
NUMBER FEMALE	1	N	23	R
START TIME	4	N	24-27	R
STOP TIME	4	N	28-31	R
PERCENT TIME FISHING	2	N	32-33	R
OPINION OF FISHERY	1	N	34	R
NUMBER AGED LT 18	1	N	35	R
NUMBER AGED 18-60	1	N	36	R
NUMBER AGED GT 60	1	N	37	R
RAMP	2	N	38-39	R
RESIDENCE	2	N	40-41	R
YEARS FISHED	1	N	42	R
FREQUENCY FISHED	1	N	43	R
WALLEYE TAKEN	2	N	44-45	R
WAL TAKEN W/TAG	1	N	46	R
WAL RELEASED	2	N	47-48	R
WAL RELEASED	1	N	49	R
SQUAWFISHTAKEN	2	N	50-51	R
SQF TAKEN W/TAG	1	N	52	R
SQF RELEASED	2	N	53-54	R
SQF RELEASED W/TAGN	1	N	55	R
SMALLMOUTH TAKEN	2	N	56-57	R
SMB TAKEN W/TAG	1	N	58	R
SMB RELEASED	2	N	59-60	R
SMB RELEASED W/TAGN	1	N	61	R
STURGEON UNDER	2	N	62-63	R
STURGEON OVER	2	N	64-65	R
STG LEGAL TAKEN	2	N	66-67	R
STG LEGAL RELEASED	2	N	68-69	R
DOCUMENT NUMBER (1986 ONLY)	4	N	70-73	R
CHANNEL CATS TAKEN	3	N	74-76	R
CHANNEL CATS RELEASED	3	N	77-79	R
DOCUMENT NUMBER	4	N	83-85	R

Angler Interview Variable Descriptions and Data Codes

Location: Place sampled (as in angler counts)

Date: Date of sample (as in angler counts)

Period: Time intervals (as in angler counts)

Day type: (as in angler counts)

Interview time: Time of angler interview (Military)

Angler type: Kind of angler interviewed
    1 = Bank
    2 = Boat

Species Sought: Species angler was trying to catch
    1 = Walleye
    3 = Smallmouth bass
    4 = White sturgeon
    5 = Shad
    6 = Catfish
    7 = Other
    8 = Non-fishing party

Trip code: Completed fishing or not
    0 = Complete
    1 = Incomplete

Number of anglers: Total number interviewed

Number male:

Number female:

Start time: Time started fishing (Military)

Stop time: Time stoped fishing (Military)

Percent time fishing: Continuous = Stop - Start times

Opinion of fishery: (Of todays fishing)
    1 = satisfactory
    2 = unsatisfactory

Number anglers aged LT 18:

Number anglers aged 18 - 60:

Number anglers aged GT 60:

Ramp: Place where interview occurred

```
    JD = John Day River
    IG = Irrigon grain elevator
    IM = Irrigon marina
    UM = Umatilla marina
    PL = Plymouth Island
    PS = Paterson Slough
    PR = Paterson Road
```

Residence:
```
    (State)
    1 = Oregon
    2 = Washington
    3 = Idaho
    4 = Other
    (Distance traveled)
    1 = 1 to 10 miles
    2 = 11 to 50 miles
    3 = GT 50 miles
```

Years fishing experience: How many years fishing this reservoir
```
    1 = First year
    2 = 2 to 5 years
    3 = GT 5 years
```

Frequency fished: How often per year in this reservoir
```
    1 = LT 5 trips
    2 = 5 to 10 trips
    3 = GT 10 trips
```

The rest of the variables in this data set are numbers of fish per type except the Document number variables

Number of walleye taken:
Number of walleye taken with tag:
Number of walleye released:
Number of walleye released with tag:
Number of squawfish taken:
Number of squawfish taken with tag:
Number of squawfish released:
Number of squawfish released with tag:
Number of smallmouth taken:
Number of smallmouth taken with tag:
Number of smallmouth released:
Number of smallmouth released with tag:
Number of undersized white sturgeon:
Number of oversized white sturgeon:
Number of legal sized white sturgeon taken:
Number of legal sized white sturgedn released:
Document number: Number assigned to each sample.
Number of channel catfish taken:
Number of channel catfish released:
Document number: Number assigned to each sample.

This documentation is the first of six files on this tape: an
information file. This tape contains annuli count and measurements on
scales of fish collected yearly from the John Day Pool of the Columbia
River by the Oregon Department of Fish and Wildlife (ODFW) from 1983 to
1986. This data was used to estimate age and growth, recruitment and
mortality of resident predators of juvenile salmonids in the study area.
Scales were read and interpreted by the ODFW who collected most of the
samples during field sampling. A sub- sample of scales collected by the
U.S. Fish and Wildlife Service was incorporated into the scales read
 (Files 2-6 on this tape) These studies were funded by the Bonneville
Power Administration (BPA). Annual and final reports of these studies
are availible from BPA.

Files 2-6 contain only data. Files l-4 are written in ASCII,
Record Format = fixed block, Logical Record Length = 80, Blocksize =
9040 and Density = 1600 bites per inch. Files 5 and 6 have the same
parameters as files l-4 except Logical Record Length = 100 and Blocksize
=9900. Programs to write disk files from the BPA mainframe computer OS
data sets to this tape using the ROSCOE environment in use during 1988
are :

```
//PJI814T JOB ('PJI ,NJ9 , ,F11PM ,PF200'),'RAYB 657-2036',
//          CLASS=S,REGION=75K,
//          MSGCLASS=E
//*ROUTE   PRINT RSCS41
//*
//*
//S1      EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1   DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.TAPE3,
//          DISP=SHR
//SYSUT2   DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.TAPE3,
//          UNIT=TAPE,
//          LABEL=(1,NL,,,EXPDT=98000),
//          DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//          VOL=(,RETAIN,,,SER=X90977),
//          DISP=NEW
//SYSIN    DD DUMMY
//*
//S2      EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1   DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.AGE2,
//          DISP=SHR
//SYSUT2   DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.AGE2,
//          UNIT=TAPE,
//          LABEL=(2,NL,,,EXPDT=98000),
//          DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//          VOL=SER=X90977,
//          DISP=NEW
//SYSIN    DD DUMMY
//*
//S3      EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1   DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.AGE3,
//          DISP=SHR
//SYSUT2   DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.AGE3,
//          UNIT=TAPE,
//          LABEL=(3,NL,,,EXPDT=98000),
//          DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//          VOL=SER=X90977,
//          DISP=NEW
//SYSIN    DD DUMMY
//*
//S4      EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1   DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.AGE4,
//          DISP=SHR
//SYSUT2   DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.AGE4,
//          UNIT=TAPE,
//          LABEL=(4,NL,,,EXPDT=98000),
//          DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//          VOL=SER=X90977,
//          DISP=NEW
//SYSIN    DD DUMMY
//*
//S5      EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1   DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.AGE5,
//          DISP=SHR
//SYSUT2   DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.AGE5,
//          UNIT=TAPE,
//          LABEL=(5,NL,,,EXPDT=98000),
//          DCB=(RECFM=FB,LRECL=100,BLKSIZE=9900,OPTCD=Q,DEN=3),
//          VOL=SER=X90977,
//          DISP=NEW
//SYSIN    DD DUMMY
//*
//S6      EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1   DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.AGE6,
//          DISP=SHR
//SYSUT2   DD DSN=PJI.PF200.RCB.NIGRO.ODFW8212.AGE6,
//          UNIT=TAPE,
//          LABEL=(6,NL,,,EXPDT=98000),
//          DCB=(RECFM=FB,LRECL=100,BLKSIZE=9900,OPTCD=Q,DEN=3),
//          VOL=SER=X90977,
//          DISP=NEW
//SYSIN    DD DUMMY
```

Age Data Variable List

VARIABLE	NUMBER OF CHARACTERS	ALPHA OR NUMERIC	COLUMNS	JUSTIFICATION
SPECIES	3	A	1-3	R
SCALE CARD NUMBER	3	A-N	4-6	R
YEAR	2	N	7-8	R
LOCATION	3	A	9-11	R
FORK LENGTH	3	N	12-14	R
FORK LENGTH INTERVAL	3	N	15-17	R
SLOT NUMBER	2	N	18-19	R
RANDOM OR SELECTED	1	A	20	R
DATE COLLECTED	6	N	21-26	R
SEX	1	A	27	R
ENVELOPE NUMBER	4	A-N	28-31	R
MEASUREMENT TO A 1	3	N	32-34	R
MEASUREMENT TO A 2	3	N	35-37	R
MEASUREMENT TO A 3	3	N	38-40	R
MEASUREMENT TO A 4	3	N	41-43	R
MEASUREMENT TO A 5	3	N	44-46	R
MEASUREMENT TO A 6	3	N	47-49	R
MEASUREMENT TO A 7	3	N	50-52	R
MEASUREMENT TO A 8	3	N	53-55	R
MEASUREMENT TO A 9	3	N	56-58	R
MEASUREMENT TO A 10	3	N	59-61	R
MEASUREMENT TO A 11	3	N	62-64	R
MEASUREMENT TO A 12	3	N	65-67	R
MEASUREMENT TO A 13	3	N	68-70	R
MEASUREMENT TO A 14	3	N	71-73	R
TOTAL SCALE RADIUS	3	N	74-76	R
AGE ASSIGNED	2	N	77-78	R
AGE INCREASE BY ONE (1985 AND 1986 ONLY)	1	A	79	R
MEASUREMENT TO A 15	3	N	80-82	R
MEASUREMENT TO A 16	3	N	83-85	R
MEASUREMENT TO A 17	3	N	86-88	R

Age Data Variable Descriptions and Data Codes

Species :
  WAL = Walleye
  SQF = Northern Squawfish
  SMB = Smallmouth bass

Scale card number: Number on upper left corner of **gummed** card
                    with scale samples mounted for impression

Year: Year in which sample was collected

Location: Place where sample was collected
  UPP = Upper John Day Pool
  LOW = Lower John Day Pool

Fork Length: Fork length of fish

Fork Length Interval: Fork length group for analysis

Slot number: Position of sample on gummed card

Random or selected: Which way was sample chosen
  A = Random (without giving a damn for sex)
  S = Selected (with respect for sex)

Date collected: Date of sample. (format Day, Month, Year)

Sex:
  M = Male
  F = Female
  U = Unknown

Envelope number: Number appearing on outside of collection envelope

Measurements to **Annuli:** Measurements are the distance from the center
                            of the focus of the scale to the outside
                            circulus of the **annulus** formation.

Total Scale Radius: Distance from the center of the focus to the
                     outside edge of the scale.

Age assigned: Age **determined by reader(s).**
               (Number of **annuli** observed)

Age increase by one: If there was evidence of another **annulus** near
                      the edge, but it could not be seen, a **'P'** was
                      entered in this column. If not, column was left
                      blank.

RADIOTELEMETRY DATA

This documentation is the first of three files on this tape; an information file. This tape contains radiotelemetry observations of walleye and northern squawfish from the John Day Pool of the Columbia River by the Oregon Department of Fish and Wildlife (ODFW) and the U.S. Fish and Wildlife Service in 1984 and 1985. This data was used together with regular field sampling to determine the distribution and movement of resident predators of juvenile salmonids in the study area. These studies were funded by the Bonneville Power Administration (BPA). Annual and final reports of these studies are available from BPA.

Files 2-3 contain only data. Files l-2 are written in ASCII, Record Format = fixed block, Logical Record Length = 80, Blocksize = 9040 and Density = 1600 bites per inch. File 3 has the same parameters as files l-2 except Logical Record Length = 133 and Blocksize = 9044. Programs to write disk files from the BPA mainframe computer OS data sets to this tape using the ROSCOE environment in use during 1988 are:

```
//PJI848T JOB ('PJI ,PF200'),'ELLIOTT 657-2036',
//         CLASS=S,REGION=75K,
//         MSGCLASS=E
//*ROUTE    PRINT RSCS41
//*
//S1        EXEC PGM=IEBGENER
//SYSPRINT  DD SYSOUT=*
//SYSUT1    DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.TAPE4,
//         DISP=SHR
//SYSUT2    DD DSN=PJI848,
//         UNIT=TAPE,
//         LABEL=(1,NL,,,EXPDT=98000),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//         VOL=(,RETAIN,,,SER=X90977),
//         DISP=NEW
//SYSIN     DD DUMMY
//*
//S2        EXEC PGM=IEBGENER
//SYSPRINT  DD SYSOUT=*
//SYSUT1    DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.TELEM84,
//         DISP=SHR
//SYSUT2    DD DSN=PJI848,
//         UNIT=TAPE,
//         LABEL=(2,NL,,,EXPDT=98000),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=9040,OPTCD=Q,DEN=3),
//         VOL=SER=X90977,
//         DISP=NEW
//SYSIN     DD DUMMY
//*
//S3        EXEC PGM=IEBGENER
//SYSPRINT  DD SYSOUT=*
//SYSUT1    DD DSN=PJI.PF200.JCE.NIGRO.ODFW8212.TELEM85W,
//         DISP=SHR
//SYSUT2    DD DSN=PJI848,
//         UNIT=TAPE,
//         LABEL=(3,NL,,,EXPDT=98000),
//         DCB=(RECFM=FB,LRECL=133,BLKSIZE=9044,OPTCD=Q,DEN=3),
//         VOL=SER=X90977,
//         DISP=NEW
//SYSIN     DD DUMMY
//*
```

Radiotelemetry Data Variable List
1984 Data Set

VARIABLE	NUMBER OF CHARACTERS	ALPHA OR NUMERIC	COLUMNS	JUSTIFICATION
SPECIES	3	A	1-3	R
FREQUENCY	5	N	5-9	R
JULIAN DATE	3	N	11-13	R
SAMPLING WEEK	2	N	15-16	R
MONTH	2	N	18-19	R
DAY	2	N	20-21	R
YEAR	2	N	22-23	R
X-COORDINATE	3	N	27-29	R
Y-COORDINATE	2	N	30-31	R
NEW X-COORDINATE	3	N	33-35	R
NEW Y-COORDINATE	3	N	36-38	R
RIVER MILE	4	N	40-43	R
Z-CODE	1	N	45	R
HABITAT	1	N	47	R
TRACK METHOD	1	N	49	R

Radiotelemetry Variable Descriptions and Data Codes
1984 Data Set

Species:
    WAL = Walleye
    SQF = Northern squawfish

Frequency: Frequency (in MHz) of radiotransmitter

Julian date: Date of sample. (format Day, Month, Year)

Sampling week: A number assigned to each Sunday - Saturday period

Week	Dates	Week	Dates
20	3/25-3/31	40	8/12-8/18
21	4/01-4/07	41	8/19-8/25
22	4/08-4/14	42	8/26-9/01
23	4/15-4/21	43	9/02-9/08
24	4/22-4/28	44	9/09-9/15
25	4/29-5/05	45	9/16-9/22
26	5/06-5/12	46	9/23-9/29
27	5/13-5/19	47	9/30-10/06
28	5/20-5/26	48	9/07-10/13
29	5/27-6/02	49	9/14-10/20
30	6/03-6/09	50	9/21-10/27
31	6/10-6/16	51	9/28-11/03
32	6/17-6/23	52	10/04-11/10
33	6/24-6/30	53	11/11-11/17
34	7/01-7/07	54	11/18-11/24
35	7/08-7/14	55	11/25-12/01
36	7/13-7/21	56	12/02-12/08
37	7/22-7/28	57	12/09-12/15
38	7/29-8/04	58	12/16-12/22
39	8/05-8/11	59	12/23-12/31

Month: (Calendar)

Day: (Calendar)

Year: (Calendar)

X-Coordinate: Field mapping system to pinpoint fish location
                 (1000 ft on a side)
Y-Coordinate: Field mapping system to pinpoint fish location
                 (1000 ft on a side)

New X-Coordinate: (Same as X-Coordinate)

New Y-Coordinate: (Needed to increase Y-Coordinate to a 3-coumn
                    variable after fish moved into areas where
                    the range in Y increased to over 99
River mile: (To the nearest 1/10th of a mile)

Z-Code: Zone (section) of the river
    1 = Upper (river mile 277-292)
    1 = Middle (river mile 252-276)
    1 = Lower (river mile 215-251)

Habitat:
    1 = Embayment or backwater
    2 = Tributary
    3 = Main channel

Track method: Place or vehicle from which tracking ocurred
    1 = Aerial
    2 = Boat
    3 = Shore
    4 = Dam
    5 = Location determined by other means than radiotelemetry
        (Capture by sampling gear or sport angler)

Radiotelemetry Data Variable List
1985 Data Set

VARIABLE	NUMBER OF CHARACTERS	ALPHA OR NUMERIC	COLUMNS	JUSTIFICATION
CARD NUMBER	4	N	1-4	R
OBSERVATION NUMBER	2	N	5-6	R
MONTH	2	N	7-8	R
DAY	2	N	9-10	R
YEAR	2	N	11-12	R
TRACK METHOD	2	N	13-14	R
START TIME	4	N	15-18	R
STOP TIME	4	N	19-22	R
RIVER MILES (FROM)	3	N	23-25	R
RIVER MILES (TO)	3	N	26-28	R
SPECIES	3	A	29-31	R
FREQUENCY	5	N	32-36	R
RIVER	1	N	37	R
CONTACT TIME	4	N	38-41	R
X-COORDINATE	3	N	42-44	R
SUB X-COORDINATE	1	N	45	R
Y-COORDINATE	3	N	46-48	R
SUB Y-COORDINATE	1	N	49	R
RIVER MILE	4	N	50-53	R
DEPTH	3	N	54-56	R
FLOW	3	N	57-59	R
HABITAT	1	N	60	R
SHORE	1	N	61	R
INSHORE-OFFSHORE	1	N	62	R

Radiotelemetry Variable Descriptions and Data Codes
1985 Data Set

Card number: Number assigned to each data sheet

Observation number: Position of observation on a card

Month: (Calendar)

Day: (Calendar)

Year: (Calendar)

Track method: Place or vehicle from which tracking ocurred
   1 = Aerial
   2 = Boat
   3 = Shore
   4 = Dam
   5 = Location determined by other means than radiotelemetry
       (Capture by sampling gear or sport angler)

Start time: Time started tracking (Military)

Stop time: Time stopped tracking (Military)

River mile (from) :   Started tracking (To the nearest 1/10th of a mile)

River mile (to):   Stopped tracking (To the nearest 1/10th of a mile)

Species:
   WAL = Walleye
   SQF = Northern squawfish

Frequency: Frequency (in MHz) of radiotransmitter

River: River inwhich observation occurred

Contact time: Time of observation (Military)

X-Coordinate: Field mapping system to pinpoint fish location
               (1000 ft on a side)

Sub X-Coordinate: (Finer division of x) (Creates 1/16th coordinate
                    square when combined with Sub-Y)
   1 = (First 250 ft of side)
   2 = (Second 250 ft of side)
   3 = (Third 250 ft of side)
   4 = (Fourth 250 ft of side)

Y-Coordinate: Field mapping system to pinpoint fish location
                (1000 ft on a side)

Sub Y-Coordinate: (Finer division of Y) (Creates 1/16th coordinate
                    square when combined with Sub-X)
    1 = (First 250 ft of side)
    2 = (Second 250 ft of side)
    3 = (Third 250 ft of side)
    4 = (Fourth 250 ft of side)

River mile: (To the nearest 1/10th mile)

Depth: Depth of fish (in feet)

Flow: Measured at location (in cfs)

Habitat:
    1 = Embayment or backwater
    2 = Tributary
    3 = John Day Dam Tailrace
    4 = McNary Dam Tailrace
    5 = Transition zone (between McNary tailrace and John Day forebay)
    6 = John Day Dam Forebay

Track method: Place or vehicle from which tracking ocurred
    1 = Aerial
    2 - Boat
    3 - Shore
    4 = Dam
    5 = Location determined by other means than radiotelemetry
        (Capture by sampling gear or sport angler)